(12)

WT-9004(EX)
EXTRACTED VERSION

GENERAL REPORT ON WEAPONS TESTS

External Neutron Measurements 1946 through 1956

Wendell A. Biggers
Freeman Waddell
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

8 October 1957

NOTICE:

This is an extracted version of WT-9004, General Report on Weapons Tests, External Neutron Measurements 1946 through 1956.

Approved for public release; distribution is unlimited.

Extracted version prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, DC 20305-1000

10 February 1987

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

AD-A995 477

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S): WT-9004(EX)
6a. NAME OF PERFORMING ORGANIZATION: Los Alamos Scientific Laboratory; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: Defense Nuclear Agency
6c. ADDRESS (City, State, and ZIP Code): Los Alamos, New Mexico	7b. ADDRESS (City, State, and ZIP Code): Washington, DC
8a. NAME OF FUNDING/SPONSORING ORGANIZATION; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification) General Report on Weapons Tests - External Neutron Measurements 1946 through 1956, Extracted Version.

12. PERSONAL AUTHOR(S) Wendell A. Biggers and Freeman Waddell

13a. TYPE OF REPORT	13b. TIME COVERED FROM ____ TO ____	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
		571008	93

16. SUPPLEMENTARY NOTATION This report has had sensitive military information removed in order to provide an unclassified version for unlimited distribution. The work was performed by the Defense Nuclear Agency in support of the DoD Nuclear Test Personnel Review Program.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	CROSSROADS Weapons
18	3		REDWING

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: DR. SIRAJ KHAN	22b. TELEPHONE (Include Area Code): 202-325-1131; 22c. OFFICE SYMBOL: ISCM

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

FOREWORD

Classified material has been removed in order to make the information available on an unclassified, open publication basis, to any interested parties. The effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is either currently classified as Restricted Data or Formerly Restricted Data under the provisions of the Atomic Energy Act of 1954 (as amended), or is National Security Information, or has been determined to be critical military information which could reveal system or equipment vulnerabilities and is, therefore, not appropriate for open publication.

The Defense Nuclear Agency (DNA) believes that though all classified material has been deleted, the report accurately portrays the contents of the original. DNA also believes that the deleted material is of little or no significance to studies into the amounts, or types, of radiation received by any individuals during the atmospheric nuclear test program.

WT-9004

GENERAL REPORT ON WEAPONS TESTS

EXTERNAL NEUTRON MEASUREMENTS 1946 THROUGH 1956

Issuance Date: October 8, 1957

LOS ALAMOS SCIENTIFIC LABORATORY
UNIVERSITY of CALIFORNIA

WT-9004

EXTERNAL NEUTRON MEASUREMENTS 1946 THROUGH 1956

By

Wendell A. Biggers

and

Freeman Waddell

Los Alamos Scientific Laboratory
Los Alamos, New Mexico

March 1957

ABSTRACT

This report summarizes field data on neutron threshold detector measurements taken by LASL Group J-12 from Operation Crossroads through Operation Redwing.

CONTENTS

FIGURES

TABLES

Chapter 1

INTRODUCTION

For some time a need has been apparent for a report summarizing the threshold neutron measurements made on nuclear tests. This report gives the results of the measurements made by Group J-12 of Los Alamos Scientific Laboratory and covers those operations from Crossroads through Redwing* (Table 1.1). Yields listed are usually the radiochemistry yields, but in a few instances the analytic (fireball) yield is used. The yields quoted are those considered appropriate at the time each table was made and are subject to minor changes.

Most of the measurements included herein were made with threshold and thermal neutron detectors. Because data from more than one shot are plotted on the same graph, all points are not plotted on the curves in cases where certain points might have led to confusion. In addition to data from threshold and thermal neutron detectors, data from the nuclear plate (Phonex) and function-of-time experiments are shown.

The main purpose of this report is to compile a large amount of data rather than to draw conclusions from such data. We hope to report on a study of neutron behavior after some rather extensive machine calculations are completed.

Machine calculations underway at present are discussed in Chapter 9, Neutron Calculations. The calculations will not be completed for some months.

---

*Other published data include: D. K. Willett et al., Upshot-Knothole Project 2.3 Report, WT-720, December 1953; T. D. Hanscome et al., Tumbler-Snapper Project 2.3 Report, WT-524, February 1953; P. S. Harris et al., Teapot Project 39.7 Report, ITR-1167, April 1955 (to be superseded by WT-1167).

TABLE 1.1

YIELDS OF SHOTS ON WHICH THRESHOLD NEUTRON MEASUREMENTS HAVE BEEN MADE

Operation	Year	Test Location	Shot Designation	Device Name	Yield, kt
Crossroads	1947	Pacific	Able		22
Sandstone	1946	Pacific	X-ray		36.5
			Yoke		46.7
			Zebra		18.2
Ranger	1951	Nevada	Able		1.27
			Baker I		7.83
			Easy		1.00
			Baker II		7.98
			Fox		22.2
Greenhouse	1951	Pacific	Dog		
			Easy		46.7
			George		
			Item		
Buster	1951	Nevada	Baker		3.49
			Charlie		14.0
			Dog		21.0
			Easy		31.4
Jangle	1951	Nevada	Sugar		1.19
			Uncle		1.22
Tumbler	1952	Nevada	1		1.055
			2		1.17
			3		30.7
Snapper	1952	Nevada	1		19.2
			2		12.0
			3		11.1
			4		14.6
			5		13.9
Ivy	1952	Pacific	Mike		1.04×10^4 [a]
			King		540
Upshot-Knothole	1953	Nevada	1		16.5
			2		24.2
			3		0.22
			5		0.21
			6		23.0
			7		41.8
			10		14.9

TABLE 1.1 (continued)

Operation	Year	Test Location	Shot Designation	Device Name	Yield, kt
Castle	1954	Pacific	Bravo		1.5×10^{4} [a]
			Romeo		1.1×10^{4} [a]
			Union		7.0×10^{3} [a]
			Yankee		1.35×10^{4} [a]
			Nectar		1.7×10^{3} [a]
Teapot	1955	Nevada			8.1
					3.6
					2.39
					3.2
Redwing	1956	Pacific	Lacrosse		37.8
			Erie		
			Seminole		13.3
			Blackfoot		
			Osage		

a. Analytic yield.

Chapter 2

EXPERIMENTAL DETAILS

The threshold detectors employed and some of their characteristics are listed in Table 2.1. Detectors other than those listed have been used on occasion but no acceptable results were obtained.

Detectors were usually placed in a radial line from ground zero and attached to a cable to facilitate recovery (Fig. 2.1). At times the terrain or other conditions made this impossible and other means of recovery were used. Care was taken to assure that samples had as clear a view of the zero point as possible and that they were oriented facing the zero position.

On several special experiments, samples were placed behind shields, in foxholes, buildings, tanks, etc. Some of these measurements were made at the request of biomedical experimenters and some were made to furnish information related to diagnostic experiments. Data relating to biomedical experiments are tabulated in Chapter 7. Data from Phonex, neutron flux vs time, and other experiments are given in Chapter 8.

More experimental details may be found in the following reports: G. A. Linenberger and W. E. Ogle, Sandstone Report, Vol. 18, Annex 4, Part I, and W. E. Ogle and W. A. Biggers, Addendum to Sandstone Vol. 18; C. L. Cowan et al., Buster-Jangle Project 10.8 Report, WT-416, June 1952; C. L. Cowan, Tumbler-Snapper Projects 17.1 and 17.2 Report, WT-555, June 1952; W. A. Biggers and L. J. Brown, Upshot-Knothole Project 17.1 Report, WT-826, March 1955; W. A. Biggers et al., Castle Project 14.1 Report, WT-952, October 1955; W. A. Biggers et al., Teapot Program 12 Report, WT-1201, June 1955; W. A. Biggers et al., Los Alamos Scientific Laboratory Report LAB-J-2101, February 1951 (internal Los Alamos report).

TABLE 2.1

THRESHOLD DETECTORS EMPLOYED

Detector	Reaction	Approximate Effective Threshold (Mev)	Half-life
Au^{197}	n, γ	Thermal	2.7 days
In^{115}	n, γ	Thermal	54 min
As^{75}	n, γ	Thermal	26.8 hr
Ta^{181}	n, γ	Thermal	117 days
S^{32}	n, p	3	14.3 days
I^{127}	n, 2n	9.5	13 days
As^{75}	n, 2n	10.5	17.5 days
Zr^{90}	n, 2n	12.5	78 hr
I^{127}	γ, n	9.5	13 days

Fig. 2.1 Typical threshold detector station, showing cable.

Chapter 3

THERMAL NEUTRON MEASUREMENTS

The thermal neutron detectors were usually exposed in pairs, one bare and one shielded with approximately 0.04 in. of cadmium. The difference between the activities of these two samples is the activity due to those neutrons below the cadmium cut-off and should be proportional to the flux of neutrons in this energy range. We call these neutrons "slow neutrons." Occasionally a third sample, shielded with cadmium and indium, is also exposed. The difference between its activity and the activity of the cadmium-shielded sample is proportional to the flux of neutrons in the indium resonance. These samples were calibrated in the Los Alamos standard graphite pile. As used in regard to low energy neutrons, "flux" is the equivalent NVT in the above mentioned pile which would give the same activation to the sample. N is the neutron density, V is the neutron velocity, and T is time.

Most of the data included herein are from measurements with gold. Tantalum was frequently used to back up gold in the event that a late recovery might make the gold samples useless. Arsenic was used as a thermal neutron detector only a few times and indium was used only when a very prompt recovery was foreseen.

In looking at the plots of thermal neutron data, one observes two regions of space in which quite different e-folding distances are exhibited. It is believed that the longer of these is due to those neutrons escaping the device with a relatively small loss in energy, while the shorter one is due to those neutrons escaping from the bomb with energies corresponding to the temperature of the high explosive after the nuclear reaction or ~0.5 to 1.0 kev.

Data on slow neutrons are given in Tables 3.1 through 3.14 and in Figs. 3.1 through 3.18. Data are presented in chronological sequence, by operation.

TABLE 3.1

SLOW NEUTRONS MEASURED WITH ARSENIC AND ANTIMONY ON OPERATION SANDSTONE

R, meters	Arsenic Values, neutrons/cm^2/kt	Antimony Values, neutrons/cm^2/kt
	X-ray (radiochemistry yield = 36.5 kt)	
558	2.79×10^{10}	
558	2.16×10^{10}	4.27×10^{10}
739	6.71×10^{9}	
739	6.71×10^{9}	1.37×10^{10}
922	1.65×10^{9}	
922	1.13×10^{9}	
	Yoke (radiochemistry yield = 48.7 kt)	
366	4.60×10^{11}	8.03×10^{11}
820	4.00×10^{9}	7.52×10^{9}
1002	1.26×10^{9}	1.29×10^{9}
	Zebra (radiochemistry yield = 18.2 kt)	
183		9.12×10^{11}
382	3.51×10^{11}	4.28×10^{11}
543	3.08×10^{10}	8.08×10^{10}
735	5.99×10^{9}	5.16×10^{9}
917	1.27×10^{9}	

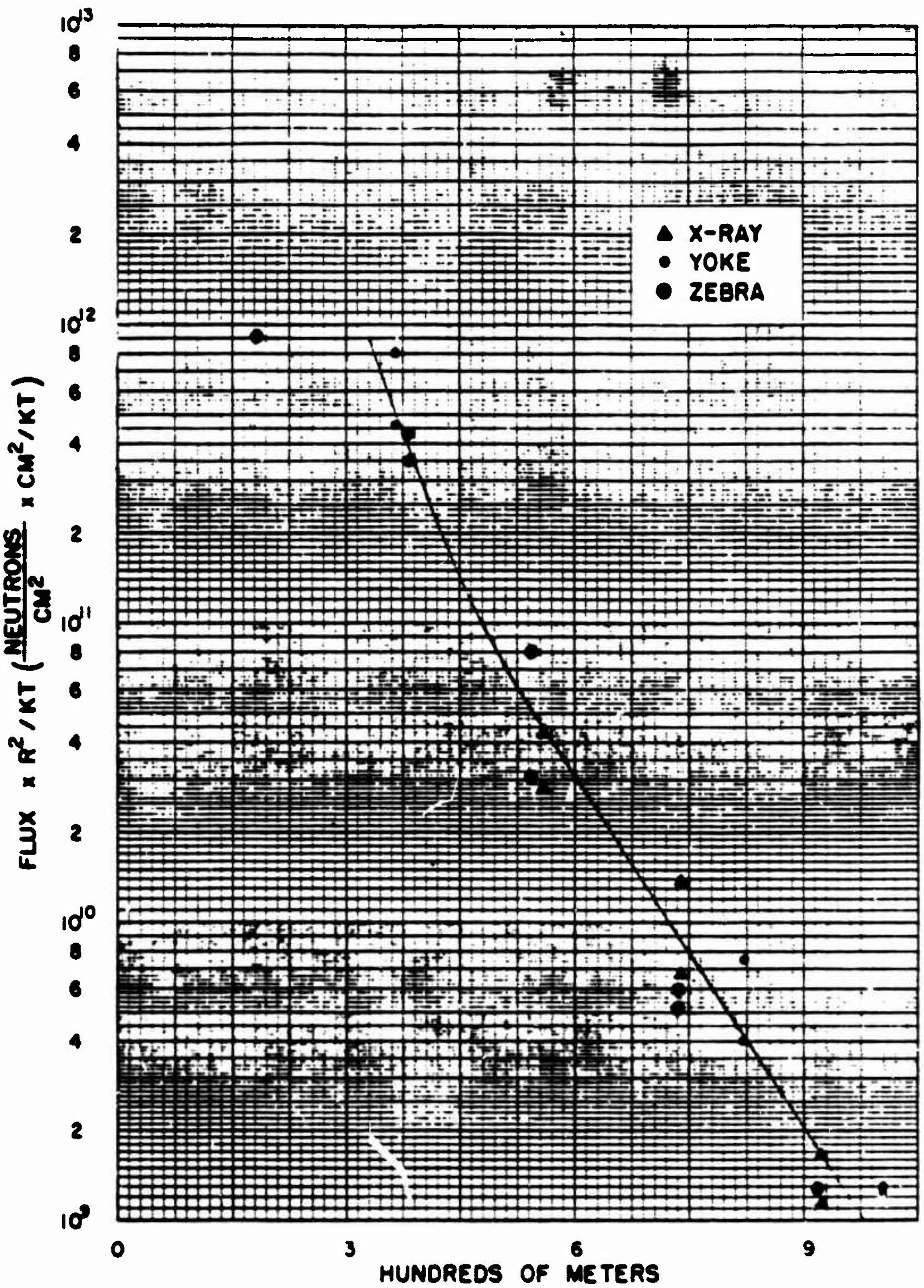

Fig. 3.1 Slow neutrons measured with arsenic and antimony on Operation Sandstone.

TABLE 3.2

SLOW NEUTRONS MEASURED WITH GOLD ON OPERATION RANGER

R, meters	Neutrons/cm²/kt
Able (radiochemistry yield = 1.27 kt)	
324[a]	7.54×10^{11}
331	6.09×10^{11}
362	3.48×10^{11}
413	1.48×10^{11}
439	5.50×10^{10}
545	2.35×10^{10}
621	1.07×10^{10}
700	5.50×10^{9}
783	2.81×10^{9}
866	1.46×10^{9}
952	8.43×10^{8}
Baker I (radiochemistry yield = 7.83 kt)	
334[b]	2.08×10^{12}
348	1.60×10^{12}
501	1.11×10^{11}
728	4.58×10^{9}
980	6.44×10^{8}
Easy (radiochemistry yield = 1.00 kt)	
333[c]	4.37×10^{11}
498	2.71×10^{10}
726	2.64×10^{9}
977	3.61×10^{8}
1326	2.20×10^{7}

TABLE 3.2 (continued)

SLOW NEUTRONS MEASURED WITH GOLD ON OPERATION RANGER

R, meters	Neutrons/cm^2/kt
Baker II (radiochemistry yield = 7.95 kt)	
373	7.30×10^{11}
471	1.66×10^{11}
686	6.48×10^{9}
933	8.08×10^{8}
1279	6.84×10^{7}
Fox (radiochemistry yield = 22.2 kt)	
450	3.25×10^{11}
526	1.53×10^{11}
640	2.52×10^{10}
856	3.60×10^{9}
1182	3.27×10^{8}
1704	1.20×10^{7}
489	2.16×10^{11}

a. Mean value of eight samples.

b. Mean value of three samples.

c. Mean value of two samples.

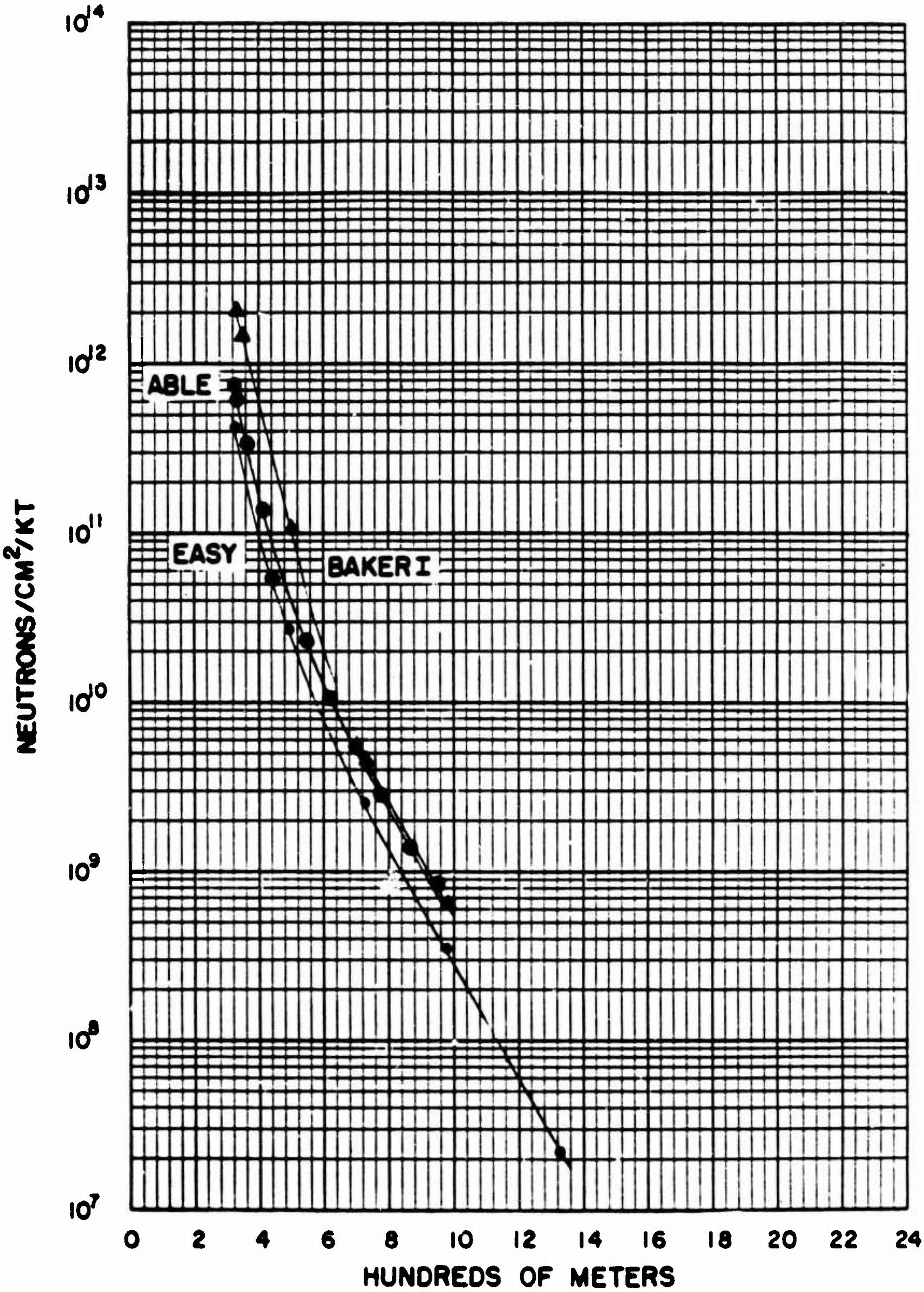

Fig. 3.2 Slow neutrons measured with gold on Able, Baker I, and Easy shots of Operation Ranger.

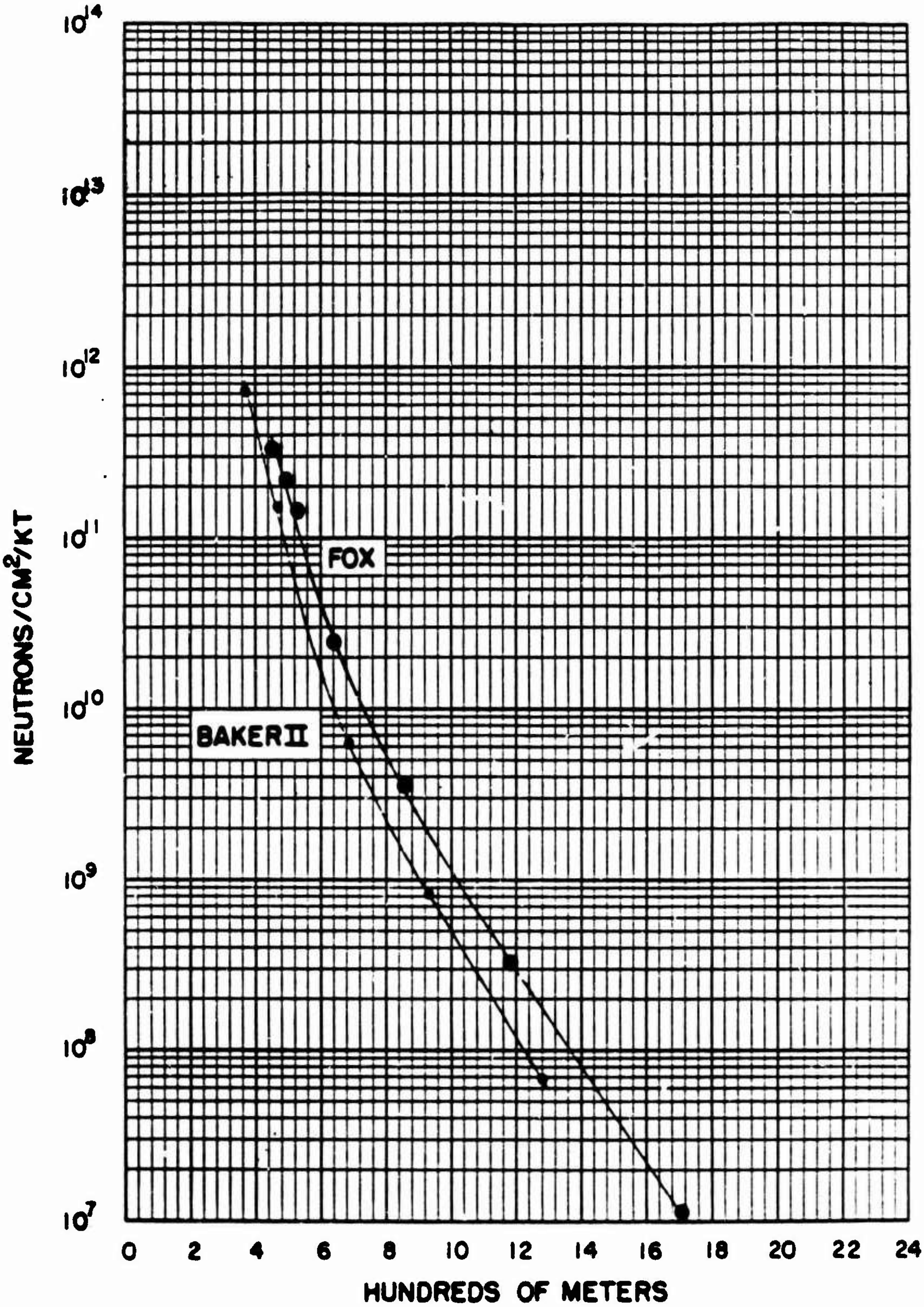

Fig. 3.3 Slow neutrons measured with gold on Baker II and Fox shots of Operation Ranger.

TABLE 3.3

SLOW NEUTRONS MEASURED WITH ARSENIC ON OPERATION RANGER

R, meters	Neutrons/cm^2/kt
Able (radiochemistry yield = 1.27 kt)	
324	6.57×10^{11}
Baker I (radiochemistry yield = 7.83 kt)	
334	1.81×10^{12}
Easy (radiochemistry yield = 1.00 kt)	
333	4.15×10^{11}
Baker II (radiochemistry yield = 7.95 kt)	
471	8.39×10^{10}
Fox (radiochemistry yield = 22.2 kt)	
450	1.11×10^{11}
526	3.37×10^{11}

TABLE 3.4

SLOW NEUTRONS MEASURED WITH GOLD ON OPERATION GREENHOUSE

R, meters	Neutrons/cm^2/kt
Easy (radiochemistry yield = 46.7 kt)	
205.1	2.50×10^{13}
289.5	2.83×10^{12}
332	2.25×10^{12}
377	1.11×10^{12}
422	5.10×10^{11}
466	2.46×10^{11}
737	1.04×10^{10}
828	4.32×10^{9}
918	2.55×10^{9}
1009	1.27×10^{9}
1100	6.32×10^{8}
1191	3.13×10^{8}
1281	1.51×10^{8}
1373	7.73×10^{7}

Pages 30 through 65
were deleted.

Chapter 4

SULFUR MEASUREMENTS

Sulfur, being nearly a 100% isotope and available in very high purity, is a useful detector for neutron measurements. Usually a small amount of powder was irradiated and pressed into a pellet weighing about 2 grams (called small sulfur samples). This was then counted with an end-window geiger tube or scintillation counter, or in a flow counter. If extremely low activities were expected, a larger sample weighing about 40 grams (called large sulfur samples) was irradiated, melted, cast into a cylinder and placed around a geiger tube for counting. Samples placed over land and water are distinguished by being called "land sulfur" and "water sulfur."

Since sulfur has an effective threshold around 3 Mev, it makes a good tool for arriving at a number proportional to the number of neutrons in the fission spectrum. It would, of course, be useful to have reliable detectors in the 0.5 to 3 Mev region, and the fission foil detector technique developed by G. S. Hurst of Oak Ridge National Laboratory and associates may contribute much information here.

Recent measurements* of the sulfur (n, p) cross section are shown in Fig. 4.1.

For high energy neutrons "flux" is used herein to mean the equivalent time-integrated flux of 14.1 Mev neutrons that would give the same activation.

Data on sulfur measurements are given in Tables 4.1 through 4.12 and Figs. 4.2 through 4.13.

*Allen, Biggers, Prestwood, and Smith, Phys. Rev. (in press).

Pages 67 through 76 were deleted.

TABLE 4.4 (continued)

NEUTRONS MEASURED WITH SMALL SULFUR SAMPLES ON OPERATION GREENHOUSE[a]

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
	Easy (radiochemistry yield = 46.7 kt)	
205.1	2.49×10^{11}	1.05×10^{20}
224.9	1.23×10^{11}	6.22×10^{19}
245.1	1.30×10^{11}	7.81×10^{19}
266.1	8.74×10^{10}	6.19×10^{19}
289.9	7.28×10^{10}	6.12×10^{19}
311.8	5.82×10^{10}	5.66×10^{19}
331.9	4.93×10^{10}	5.43×10^{19}
354.8	3.93×10^{10}	4.95×10^{19}
376.7	3.22×10^{10}	4.57×10^{19}
400.5	2.58×10^{10}	4.14×10^{19}
421.5	2.21×10^{10}	3.93×10^{19}
443.5	1.61×10^{10}	3.17×10^{19}
466.3	1.46×10^{10}	3.17×10^{19}
556.0	5.76×10^{9}	1.78×10^{19}
641.6	2.79×10^{9}	1.15×10^{19}
737	1.24×10^{9}	6.74×10^{18}
828	6.37×10^{8}	4.37×10^{18}
927	3.19×10^{8}	2.74×10^{18}
1009	1.60×10^{8}	1.63×10^{18}
1100	8.42×10^{7}	1.02×10^{18}
1191	4.87×10^{7}	6.91×10^{17}
1281	2.71×10^{7}	4.45×10^{17}
1372	1.54×10^{7}	2.90×10^{17}

Pages 78 through 81 were deleted.

TABLE 4.6

NEUTRONS MEASURED WITH SULFUR ON OPERATION BUSTER

R, meters	Neutrons/cm²/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
Baker (radiochemistry yield = 3.49 kt)		
365.4	1.38×10^{10}	1.84×10^{19}
388.0	9.97×10^{9}	1.50×10^{19}
460.1	5.47×10^{9}	1.16×10^{19}
526.0	3.38×10^{9}	9.35×10^{18}
598.6	1.88×10^{9}	6.74×10^{18}
675.7	1.08×10^{9}	4.93×10^{18}
756.2	6.56×10^{8}	3.75×10^{18}
922.6	1.97×10^{8}	1.68×10^{18}
1009	1.20×10^{8}	1.22×10^{18}
1226	3.15×10^{7}	4.73×10^{17}
347.5 NE	1.84×10^{10}	2.22×10^{19}
345.6 NW	1.76×10^{10}	2.10×10^{19}
361.2 SW	1.55×10^{10}	2.02×10^{19}
Charlie (radiochemistry yield = 14.0 kt)		
374.9	1.19×10^{10}	1.67×10^{19}
419.7	8.21×10^{9}	1.45×10^{19}
477.8	6.11×10^{9}	1.39×10^{19}
545.2	3.31×10^{9}	9.84×10^{18}
618.9	2.03×10^{9}	7.78×10^{18}
696.7	1.10×10^{9}	5.34×10^{18}
777.4	6.11×10^{8}	3.69×10^{18}
860.4	3.57×10^{8}	2.64×10^{18}
944.6	1.95×10^{8}	1.74×10^{18}
1031	1.01×10^{8}	1.07×10^{18}
1248	1.51×10^{7}	2.35×10^{17}
1693	4.04×10^{6}	1.16×10^{17}
Dog (radiochemistry yield = 21.0 kt)		
441.2	7.90×10^{9}	1.54×10^{19}
468.7	6.62×10^{9}	1.45×10^{19}

TABLE 4.6 (continued)

NEUTRONS MEASURED WITH SULFUR ON OPERATION BUSTER

R, meters	Neutrons/cm²/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
Dog (radiochemistry yield = 21.0 kt)		
511.4	5.00×10^{9}	1.31×10^{19}
565.7	Not recovered	
628.7	Not recovered	
698.1	1.18×10^{9}	5.75×10^{18}
772.0	6.86×10^{8}	4.09×10^{18}
849.4	4.11×10^{8}	2.97×10^{18}
929.0	2.41×10^{8}	2.08×10^{18}
1011	1.18×10^{8}	1.21×10^{18}
1222	3.71×10^{7}	5.54×10^{17}
1438	1.05×10^{7}	2.17×10^{17}
441.2 NW	7.00×10^{9}	1.36×10^{19}
Easy (radiochemistry yield = 31.4 kt)		
419.1	6.69×10^{10}	1.18×10^{20}
453.6	5.61×10^{10}	1.15×10^{20}
562.4	3.01×10^{10}	9.52×10^{19}
630.3	1.56×10^{10}	6.20×10^{19}
706.9	1.25×10^{10}	6.25×10^{19}
781.6	7.39×10^{9}	4.51×10^{19}
859.4	3.82×10^{9}	2.82×10^{19}
941.2	2.60×10^{9}	2.30×10^{19}
1032	1.38×10^{9}	1.47×10^{19}
1109	8.34×10^{8}	1.03×10^{19}
1195	5.19×10^{8}	7.41×10^{18}
1282	3.16×10^{8}	5.19×10^{18}
1369	1.69×10^{8}	3.17×10^{18}
1456	1.10×10^{8}	2.33×10^{18}
1545	6.43×10^{7}	1.53×10^{18}
1634	3.31×10^{7}	8.84×10^{17}
1710	2.21×10^{7}	6.46×10^{17}
1766	1.49×10^{7}	4.65×10^{17}
1990	5.41×10^{6}	2.14×10^{17}

Pages 84 and 85 were deleted.

TABLE 4.7

NEUTRONS MEASURED WITH SULFUR ON OPERATION JANGLE

R, meters	Neutrons/cm²/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
	Sugar (radiochemistry yield = 1.19 kt)	
30.4	4.64×10^{11}	4.29×10^{18}
85.9	2.39×10^{11}	1.77×10^{19}
182.0	4.16×10^{10}	1.38×10^{19}
272.9	1.36×10^{10}	1.01×10^{19}
363.0	4.88×10^{9}	6.43×10^{18}
453.5	2.00×10^{9}	4.11×10^{18}
544.1	1.83×10^{9}	5.42×10^{18}
634.6	5.39×10^{8}	2.17×10^{18}
724.2	3.64×10^{8}	1.91×10^{18}
814.7	2.62×10^{8}	1.74×10^{18}
904.3	4.55×10^{8}	3.72×10^{18}
1086	2.84×10^{7}	3.35×10^{17}
	Uncle (radiochemistry yield = 1.22 kt)	
14.9	6.44×10^{9}	1.43×10^{16}
18.9	9.75×10^{9}	3.48×10^{16}
24.4	2.65×10^{9}	1.58×10^{16}
29.5	1.99×10^{9}	1.73×10^{16}
90.8	1.89×10^{9}	1.56×10^{17}
178.3	1.97×10^{9}	6.26×10^{17}
260.3	2.57×10^{9}	1.74×10^{18}
340.4	5.61×10^{8}	6.50×10^{17}
431.9	5.88×10^{8}	1.10×10^{18}
523.3	3.06×10^{8}	8.38×10^{17}
614.8	2.39×10^{8}	9.03×10^{17}
706.2	1.66×10^{8}	8.28×10^{17}
797.6	1.16×10^{8}	7.38×10^{17}
889.1	1.14×10^{8}	9.01×10^{17}

TABLE 4.8

NEUTRONS MEASURED WITH SULFUR ON OPERATION TUMBLER

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
	Tumbler 1 (radiochemistry yield = 1.055 kt)	
306.3	1.12×10^{10}	1.05×10^{19}
440.7	2.94×10^{9}	5.71×10^{18}
601.2	8.06×10^{8}	2.91×10^{18}
771.8	2.34×10^{8}	1.39×10^{18}
946.4	7.35×10^{7}	6.58×10^{17}
	Tumbler 2 (radiochemistry yield = 1.17 kt)	
342.0	1.06×10^{10}	1.24×10^{19}
346.6	1.07×10^{10}	1.29×10^{19}
374.9	8.09×10^{9}	1.14×10^{19}
421.5	5.72×10^{9}	1.02×10^{19}
481.0	3.29×10^{9}	7.61×10^{18}
549.6	2.24×10^{9}	6.77×10^{18}
624.5	1.05×10^{9}	4.10×10^{18}
704.1	5.66×10^{8}	2.81×10^{18}
783.6	3.26×10^{8}	2.00×10^{18}
866.9	2.32×10^{8}	1.74×10^{18}
951.9	Sample broken	
1125	9.68×10^{7}	1.23×10^{18}
1303	3.97×10^{7}	6.74×10^{17}

Page 88 was deleted.

TABLE 4.9

NEUTRONS MEASURED WITH SULFUR ON OPERATION SNAPPER

R, meters	Neutrons/cm²/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
Snapper 1 (radiochemistry yield = 19.2 kt)		
322.8	2.66×10^{11}	2.77×10^{20}
393.7	2.08×10^{11}	3.22×10^{20}
521.7	8.18×10^{10}	2.23×10^{20}
675.7	2.76×10^{10}	1.26×10^{20}
841.2	9.58×10^{9}	6.78×10^{19}
1013	2.94×10^{9}	3.02×10^{19}
1188	1.14×10^{9}	1.61×10^{19}
1365	4.06×10^{8}	7.56×10^{18}
Snapper 2 (radiochemistry yield = 12.0 kt)		
92.4	4.32×10^{12}	3.69×10^{20}
376.7	2.03×10^{11}	2.88×10^{20}
556.4	4.48×10^{10}	1.39×10^{20}
737.4	1.12×10^{10}	6.09×10^{19}
919.0	3.28×10^{9}	2.77×10^{19}
1101	1.02×10^{9}	1.24×10^{19}
1282	3.32×10^{8}	5.46×10^{18}
Snapper 3 (radiochemistry yield = 11.1 kt)		
204.8	9.82×10^{10}	4.12×10^{19}
377.2	2.28×10^{10}	3.24×10^{19}
556.4	4.98×10^{9}	1.54×10^{19}
646.5	2.63×10^{9}	1.10×10^{19}
737.5	1.32×10^{9}	7.18×10^{18}
828.0	7.94×10^{8}	5.44×10^{18}
919.0	4.59×10^{8}	3.88×10^{18}
1010	2.76×10^{8}	2.82×10^{18}
1102	1.14×10^{8}	1.38×10^{18}
1191	7.63×10^{7}	1.08×10^{18}
1284	3.71×10^{7}	6.12×10^{17}

TABLE 4.9 (continued)

NEUTRONS MEASURED WITH SULFUR ON OPERATION SNAPPER

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
Snapper 4 (radiochemistry yield = 14.6 kt)		
129.8	3.96×10^{11}	6.67×10^{18}
204.8	1.34×10^{11}	5.62×10^{18}
289.4	5.18×10^{10}	4.34×10^{18}
377.2	2.13×10^{10}	3.03×10^{18}
466.8	9.59×10^{9}	2.09×10^{18}
556.4	4.55×10^{9}	1.41×10^{18}
646.5	2.26×10^{9}	9.45×10^{18}
737.5	1.16×10^{9}	6.31×10^{18}
828.0	6.17×10^{8}	4.23×10^{18}
919.0	3.43×10^{8}	2.90×10^{18}
1010	1.90×10^{8}	1.94×10^{18}
1101	1.11×10^{8}	1.35×10^{18}
1192	5.98×10^{7}	8.50×10^{17}
1284	5.10×10^{7}	8.41×10^{17}
Snapper 5 (radiochemistry yield = 13.9 kt)		
377.2	5.87×10^{10}	8.35×10^{19}
466.8	2.66×10^{10}	5.80×10^{19}
556.4	1.31×10^{10}	4.06×10^{19}
737.5	3.46×10^{9}	1.88×10^{19}
919.0	1.01×10^{9}	8.53×10^{18}
1101	3.13×10^{8}	3.79×10^{18}
1284	1.10×10^{8}	1.81×10^{18}

Page 91 was deleted.

TABLE 4.10

NEUTRONS MEASURED WITH SULFUR ON OPERATION IVY

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
	Mike (analytic yield = 1.04×10^4 kt)	
1417	1.5×10^7	3.0×10^{17}
1554	6.1×10^6	1.5×10^{17}
1600	4.5×10^6	1.2×10^{17}
1646	4.8×10^6	1.3×10^{17}
1692	3.5×10^6	1.0×10^{17}
1783	2.2×10^6	7.0×10^{16}
1875	1.25×10^6	4.4×10^{16}
1920	2.9×10^6	1.1×10^{17}
1966	1.1×10^6	4.3×10^{16}
2057	2.2×10^6	9.3×10^{16}
2103	4.4×10^5	1.9×10^{16}
2149	3.6×10^5	1.7×10^{16}
2195	2.0×10^5	9.6×10^{15}
2240	8.1×10^7	4.1×10^{16}

Page 93 was deleted.

TABLE 4.11

NEUTRONS MEASURED WITH SULFUR ON OPERATION UPSHOT-KNOTHOLE

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times$ cm^2/kt
	UK-1 (radiochemistry yield = 16.5 kt)	
102.2	1.06×10^{12}	1.11×10^{20}
164.9	2.55×10^{11}	6.93×10^{19}
204.5	1.64×10^{11}	6.86×10^{19}
246.3	1.15×10^{11}	6.98×10^{19}
289.1	7.58×10^{10}	6.34×10^{19}
377.0	2.97×10^{10}	4.22×10^{19}
466.3	1.35×10^{10}	2.94×10^{19}
556.0	6.36×10^{9}	1.97×10^{19}
646.5	3.13×10^{9}	1.31×10^{19}
737.0	1.58×10^{9}	8.58×10^{18}
828.0	8.36×10^{8}	5.73×10^{18}
919.0	4.50×10^{8}	3.80×10^{18}
1101	1.34×10^{8}	1.62×10^{18}
1284	4.45×10^{7}	7.34×10^{17}
1466	1.41×10^{7}	3.03×10^{17}
	UK-2 (radiochemistry yield = 24.2 kt)	
246.3	2.44×10^{11}	1.48×10^{20}
289.1	1.67×10^{11}	1.40×10^{20}
377.0	6.40×10^{10}	9.10×10^{19}
466.3	2.98×10^{10}	6.48×10^{19}
556.0	1.43×10^{10}	4.42×10^{19}
646.5	7.02×10^{9}	2.93×10^{19}
737.0	3.55×10^{9}	1.93×10^{19}
828.0	1.93×10^{9}	1.32×10^{19}
919.0	1.03×10^{9}	8.70×10^{18}
1101	3.38×10^{8}	4.10×10^{18}
1284	1.15×10^{8}	1.90×10^{18}
1466	4.12×10^{7}	8.85×10^{17}

TABLE 4.11 (continued)

NEUTRONS MEASURED WITH SULFUR
ON OPERATION UPSHOT-KNOTHOLE

R, meters	Neutrons/cm²/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
	UK-5 (radiochemistry yield = 0.21 kt)	
38.1	1.61×10^{12}	2.34×10^{18}
54.9	7.48×10^{11}	2.25×10^{19}
96.0	2.83×10^{11}	2.61×10^{19}
140.8	1.22×10^{11}	2.42×10^{19}
185.6	6.05×10^{10}	2.08×10^{18}
366.7	6.43×10^{9}	8.65×10^{19}
549.6	8.81×10^{8}	2.66×10^{19}
732.4	2.82×10^{8}	1.51×10^{18}
	UK-6 (radiochemistry yield = 23.0 kt)	
204.5	1.61×10^{11}	6.73×10^{18}
246.3	1.26×10^{11}	7.64×10^{18}
289.1	7.20×10^{10}	6.02×10^{18}
332.8	4.59×10^{10}	5.08×10^{19}
377.0	2.77×10^{10}	3.94×10^{19}
421.5	2.10×10^{10}	3.73×10^{19}
466.3	1.30×10^{10}	2.83×10^{19}
556.0	6.28×10^{8}	1.94×10^{19}
646.5	3.17×10^{8}	1.32×10^{19}
737.0	1.62×10^{9}	8.80×10^{18}
828.0	9.09×10^{8}	6.23×10^{19}
919.0	4.74×10^{8}	4.00×10^{18}
1101	1.48×10^{8}	1.79×10^{18}
1284	4.70×10^{7}	7.75×10^{17}
1466	1.93×10^{7}	4.15×10^{17}

TABLE 4.11 (continued)

NEUTRONS MEASURED WITH SULFUR
ON OPERATION UPSHOT-KNOTHOLE

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
	UK-10 (radiochemistry yield = 14.9 kt)	
167.5	3.07×10^{12}	8.61×10^{20}
169.5	3.67×10^{12}	1.05×10^{21}
283.5	8.05×10^{11}	6.47×10^{20}
447.1	1.66×10^{11}	3.32×10^{20}
532.2	7.79×10^{10}	2.21×10^{20}
620.9	3.85×10^{10}	1.48×10^{20}
708.7	1.87×10^{10}	9.39×10^{19}
797.4	1.03×10^{10}	6.55×10^{19}
887.0	5.33×10^{9}	4.19×10^{19}
1067	1.54×10^{9}	1.75×10^{19}
1249	4.87×10^{8}	7.60×10^{18}
1430	1.61×10^{8}	3.29×10^{18}

Pages 97 and 98 were deleted.

TABLE 4.12

NEUTRONS MEASURED WITH SULFUR ON OPERATION CASTLE

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
	Bravo (analytic yield = 1.5×10^4 kt)	
1554	3.24×10^7	7.82×10^{17}
1646	1.89×10^7	5.12×10^{17}
1737	1.26×10^7	3.80×10^{17}
1829	9.49×10^6	3.17×10^{17}
1920	9.87×10^6	3.64×10^{17}
2012	Not recovered	
2149	2.15×10^6	9.93×10^{16}
2286[a]	4.11×10^6	2.15×10^{17}
1300[b]	8.47×10^6	1.43×10^{17}
	Romeo (analytic yield = 1.1×10^4 kt)	
1554	2.12×10^7	5.12×10^{17}
1646	1.90×10^7	5.15×10^{17}
1737	8.50×10^6	2.56×10^{17}
1829	5.89×10^6	1.97×10^{17}
1920	5.35×10^6	1.97×10^{17}
2149	9.44×10^5	4.36×10^{16}
2286[a]	No 14.3 activity	
	Union (analytic yield = 7.0×10^3 kt)	
2017	7.50×10^4	3.05×10^{15}
2109	8.23×10^4	3.66×10^{15}
2191	1.13×10^5	5.42×10^{15}
2287	7.17×10^4	3.75×10^{15}
2377	4.30×10^4	2.43×10^{15}
2469	5.51×10^4	3.36×10^{15}
2652[c]	7.77×10^4	5.46×10^{15}
2865[c]	1.61×10^4	1.32×10^{15}

TABLE 4.12 (continued)

NEUTRONS MEASURED WITH SULFUR ON OPERATION CASTLE

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
	Yankee (analytic yield = 1.35×10^4 kt)	
2017 (small)	2.33×10^5	9.48×10^{15}
2377 (small)	1.99×10^5	1.12×10^{16}
2017 (large)	2.70×10^5	1.10×10^{16}
2377 (large)	2.08×10^5	1.18×10^{16}
	Nectar (analytic yield = 1.7×10^3 kt)	
960	2.76×10^9	2.54×10^{19}
1515	9.47×10^7	2.17×10^{18}

a. On side of building, about 5 ft above ground.

b. Charlie Dome station, sample below surface of ground.

c. Only the two farthest stations were in the clear.

Page 101 was deleted.

Chapter 5

IODINE AND ARSENIC MEASUREMENTS

Iodine has proved useful in measuring high ene.gy neutrons and gamma rays. It is believed that essentially all of the gamma rays seen by iodine come from neutron capture in nitrogen and, thus, are also a measure of neutrons. The source, however, should not be interpreted as a point source, but as a large volume of air surrounding the device being tested.*

Iodine is not easily decontaminated if the sample holder has allowed entry of sea water or other contaminants. The iodine data from Operation Castle should not be considered too reliable for this reason.

Arsenic was also used on occasions for the same purpose as iodine. It, however, presented more difficulties, due mainly to its contaminants and its high cross section for thermal neutrons.

The activities due to neutrons and gamma rays were separated by using both bare and lead-shielded samples.

Data on neutron measurements with iodine are given in Tables 5.1, 5.5, 5.6, 5.8, and 5.10 and in Figs. 5.1 through 5.8. Data on neutron measurements with arsenic are given in Tables 5.2 and 5.7. Data on gamma-ray measurements are given in Tables 5.3, 5.4 and 5.9. Data are presented in chronological order, by operation.

---

*J. S. Malik, Los Alamos Scientific Laboratory Report LA-1620, July 28, 1955.

TABLE 5.1

NEUTRONS MEASURED WITH IODINE ON OPERATION SANDSTONE

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
X-ray (radiochemistry yield = 36.5 kt)		
739	2.82×10^6	1.54×10^{16}
922	6.49×10^5	5.52×10^{15}
Yoke (radiochemistry yield = 48.7 kt)		
196.7	1.61×10^9	6.23×10^{17}
366	1.54×10^8	2.06×10^{17}
820	1.09×10^6	7.33×10^{15}
1002	6.51×10^5	6.54×10^{15}
Zebra (radiochemistry yield = 18.2 kt)		
196.2	1.20×10^9	4.62×10^{17}
382	5.77×10^7	8.42×10^{16}
543	6.90×10^6	2.03×10^{16}
735	6.48×10^5	3.50×10^{15}

Page 104 was deleted.

TABLE 5.2

FAST NEUTRONS MEASURED WITH ARSENIC ON OPERATION SANDSTONE

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
	X-ray (radiochemistry yield = 36.5 kt)	
558	4.66×10^7	1.45×10^{17}
739	2.08×10^7	1.14×10^{17}
922	7.12×10^6	6.05×10^{16}
	Yoke (radiochemistry yield = 48.7 kt)	
1002	3.08×10^6	3.09×10^{16}
	Zebra (radiochemistry yield = 18.2 kt)	
917	2.20×10^6	1.85×10^{16}

TABLE 5.3

GAMMA RAYS ABOVE ~9.5 MEV MEASURED WITH IODINE ON OPERATION SANDSTONE

R, meters	Relative flux/kt	Rel. flux × R^2(cm^2)/kt
X-ray (radiochemistry yield = 36.5 kt)		
739	4.52×10^7	2.47×10^{17}
922	2.03×10^7	1.73×10^{17}
Yoke (radiochemistry yield = 48.7 kt)		
196.7	1.62×10^9	6.27×10^{17}
366	3.29×10^8	4.41×10^{17}
820	2.46×10^7	1.65×10^{17}
1002	1.13×10^7	1.13×10^{17}
Zebra (radiochemistry yield = 18.2 kt)		
196.2	1.62×10^9	6.24×10^{17}
382	3.35×10^8	4.89×10^{17}
543	1.15×10^8	3.39×10^{17}
735	3.74×10^7	2.02×10^{17}
917	1.76×10^7	1.48×10^{17}

TABLE 5.4

GAMMA RAYS ABOVE ~10.5 MEV MEASURED WITH ARSENIC ON OPERATION SANDSTONE

R, meters	Relative flux/kt	Rel. flux × R^2(cm^2)/kt
	X-ray (radiochemistry yield = 36.5 kt)	
558	8.49×10^{7}	2.64×10^{17}
739	2.88×10^{7}	1.57×10^{17}
922	1.21×10^{7}	1.03×10^{17}
	Yoke (radiochemistry yield = 48.7 kt)	
366	2.01×10^{8}	2.69×10^{17}
820	1.85×10^{7}	1.24×10^{17}
1002	7.80×10^{6}	7.83×10^{16}
	Zebra (radiochemistry yield = 18.3 kt)	
543	7.14×10^{7}	2.11×10^{17}
735	3.52×10^{7}	1.90×10^{17}
917	2.36×10^{7}	1.98×10^{17}

TABLE 5.5

NEUTRONS MEASURED WITH IODINE ON OPERATION GREENHOUSE

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
	Easy (radiochemistry yield = 46.7 kt)	
205.1	2.53×10^{9}	1.06×10^{18}
289.5	6.12×10^{8}	5.14×10^{17}
377.0	2.14×10^{8}	3.04×10^{17}
466.0	6.55×10^{7}	1.42×10^{17}
737.3	5.76×10^{6}	3.13×10^{16}
827.8	3.06×10^{6}	2.10×10^{16}
918.1	2.59×10^{6}	2.18×10^{16}
1009	6.32×10^{6}	6.42×10^{16}
1100	3.06×10^{6}	3.70×10^{16}

Pages 109 through 111 were deleted.

TABLE 5.6

NEUTRONS MEASURED WITH IODINE ON SNAPPER 1 SHOT

R, meters[a]	Neutrons/cm²/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
Snapper 1 (radiochemistry yield = 19.2 kt)		
322.8	2.20×10^{10}	2.29×10^{19}
393.7	2.24×10^{10}	3.48×10^{19}
521.7	8.93×10^{9}	2.43×10^{19}
675.7	2.84×10^{9}	1.30×10^{19}
841.2	8.98×10^{8}	6.35×10^{18}

a. 0 to 460 meters, region of large absorption by bomb mechanisms.

TABLE 5.7

FAST NEUTRONS MEASURED WITH ARSENIC ON SNAPPER 1 SHOT

R, meters[a]	Neutrons/cm²/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
Snapper 1 (radiochemistry yield = 19.2 kt)		
323.1	2.07×10^{10}	2.16×10^{19}
348.4	2.02×10^{10}	2.45×10^{19}
393.7	1.64×10^{10}	2.54×10^{19}
453.2	1.02×10^{10}	2.08×10^{19}
521.7	5.68×10^{9}	1.55×10^{19}
675.7	2.06×10^{9}	9.43×10^{18}
841.2	5.89×10^{8}	4.17×10^{18}
1013.1	2.11×10^{8}	2.17×10^{18}

a. 0 to 460 meters, region of large absorption by bomb mechanisms.

Page 113 was deleted.

TABLE 5.8

NEUTRONS MEASURED WITH IODINE ON OPERATION UPSHOT-KNOTHOLE

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
	UK-1 (radiochemistry yield = 16.5 kt)	
466.3	5.03×10^{7}	1.09×10^{17}
737.0	2.15×10^{6}	1.17×10^{16}
919.0	0[a]	0[a]
	UK-2 (radiochemistry yield = 24.2 kt)	
204.5	3.52×10^{10}	$1.47 \times 10^{[illegible]}$
289.1	1.32×10^{10}	1.10×10^{19}
377.0	5.41×10^{9}	7.69×10^{18}
466.3	2.36×10^{9}	5.13×10^{18}
556.0	1.09×10^{9}	3.37×10^{18}
646.5	5.25×10^{8}	2.19×10^{18}
737.0	2.58×10^{8}	1.40×10^{18}
919.0	6.86×10^{7}	5.79×10^{17}
1101	2.67×10^{7}	3.24×10^{17}
1284	5.41×10^{6}	8.92×10^{16}
	UK-6 (radiochemistry yield = 23.0 kt)	
289.1	4.52×10^{9}	3.78×10^{18}
377.0	1.63×10^{9}	2.32×10^{18}
556.0	3.50×10^{8}	1.08×10^{18}
646.5	1.47×10^{8}	6.14×10^{17}
828.0	4.32×10^{7}	2.96×10^{17}
	UK-10 (radiochemistry yield = 14.9 kt)	
214.9	6.15×10^{9}	2.84×10^{18}
362.1	8.26×10^{8}	1.08×10^{18}
532.2	3.07×10^{8}	8.70×10^{17}
708.7	7.72×10^{7}	3.88×10^{17}
1067	1.79×10^{7}	2.04×10^{17}

a. Below sensitivity of system.

Pages 115 and 116 were deleted.

TABLE 5.9

GAMMA RAYS ABOVE ~9.5 MEV MEASURED WITH IODINE ON OPERATION UPSHOT-KNOTHOLE

R, meters	Relative flux/kt	Rel. flux × R^2(cm^2)/kt
	UK-1 (radiochemistry yield = 16.5 kt)	
466.3	8.57×10^9	1.86×10^{19}
737.0	1.87×10^9	1.02×10^{19}
919.0	1.06×10^9	8.95×10^{18}
	UK-2 (radiochemistry yield = 24.2 kt)	
204.5	1.23×10^{11}	5.14×10^{19}
289.1	3.98×10^{10}	3.33×10^{19}
377.0	5.76×10^9	8.18×10^{18}
466.3	8.64×10^9	1.88×10^{19}
556.0	6.63×10^9	2.05×10^{19}
646.5	3.51×10^9	1.47×10^{19}
737.0	2.18×10^9	1.18×10^{19}
919.0	9.88×10^8	8.34×10^{18}
1101	3.79×10^8	4.59×10^{18}
1284	6.58×10^8	1.09×10^{19}
	UK-6 (radiochemistry yield = 23.0 kt)	
289.1	1.13×10^{11}	9.44×10^{19}
377.0	2.74×10^{10}	3.89×10^{19}
556.0	9.91×10^9	3.06×10^{19}
646.5	5.53×10^9	2.31×10^{19}
828.0	2.29×10^9	1.57×10^{19}
	UK-10 (radiochemistry yield = 14.9 kt)	
214.9	4.24×10^{10}	1.96×10^{19}
362.1	3.03×10^{10}	3.97×10^{19}
532.2	6.63×10^9	1.88×10^{19}
708.7	3.05×10^9	1.53×10^{19}
887.0	1.48×10^9	1.16×10^{19}

TABLE 5.10

NEUTRONS MEASURED WITH IODINE ON OPERATION CASTLE

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
	Bravo (analytic yield = 1.5×10^4 kt)	
1554	2.94×10^6	7.10×10^{16}
1646	1.81×10^6	4.9[illegible] $\times 10^{16}$
1737	8.93×10^5	2.69×10^{16}
1829	5.28×10^5	1.77×10^{16}
1920	4.45×10^5	1.64×10^{16}
2012	3.45×10^5	1.40×10^{16}
2149	6.39×10^4	2.95×10^{15}
2286[a]	7.47×10^4	3.90×10^{15}
	Romeo (analytic yield = 1.1×10^4 kt)	
1554	1.64×10^6	3.96×10^{16}
1646	1.35×10^6	3.66×10^{16}
1737	5.84×10^5	1.76×10^{16}
1829	4.10×10^5	1.37×10^{16}
2149	8.47×10^4	3.91×10^{15}
	Union (analytic yield = 7.0×10^3 kt)	
2017	1.96×10^4	7.97×10^{14}
2109	1.15×10^4	5.12×10^{14}
2191	2.31×10^4	1.11×10^{15}
2287	1.73×10^4	9.05×10^{14}
2377	1.37×10^4	7.74×10^{14}
2652[b]	5.44×10^3	3.83×10^{14}
	Yankee (analytic yield = 1.35×10^4 kt)	
2017	8.37×10^4	3.41×10^{15}
2377	7.78×10^4	4.40×10^{15}

TABLE 5.10 (continued)

NEUTRONS MEASURED WITH IODINE ON OPERATION CASTLE

R, meters	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
Nectar (analytic yield = 1.7×10^3 kt)		
960	4.35×10^8	4.01×10^{18}
1515	8.47×10^6	1.95×10^{17}

a. On side of building, about 5 ft above ground.

b. Only this station was in the clear.

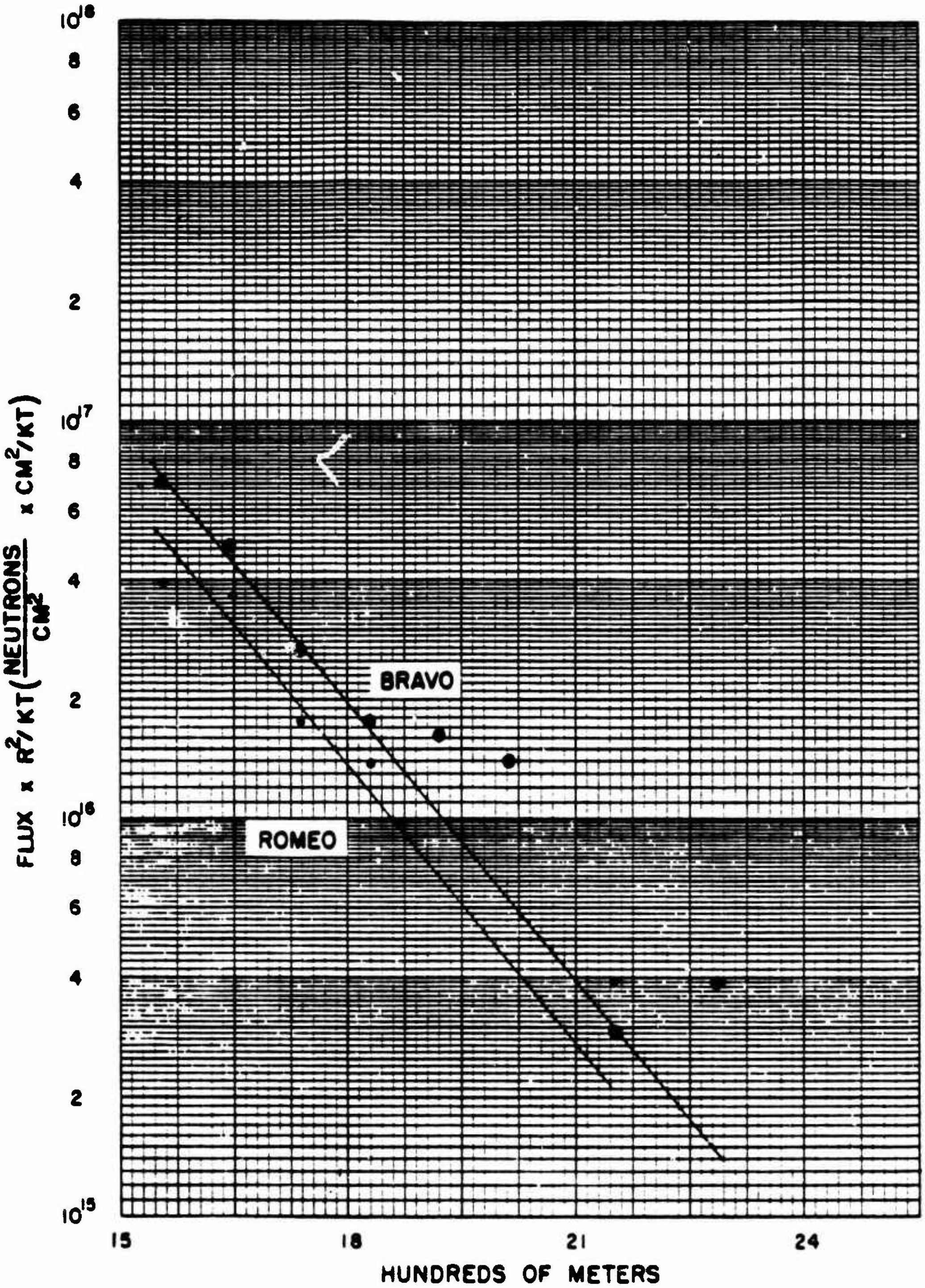

Fig. 5.7 Neutrons measured with iodine on Bravo and Romeo shots of Operation Castle.

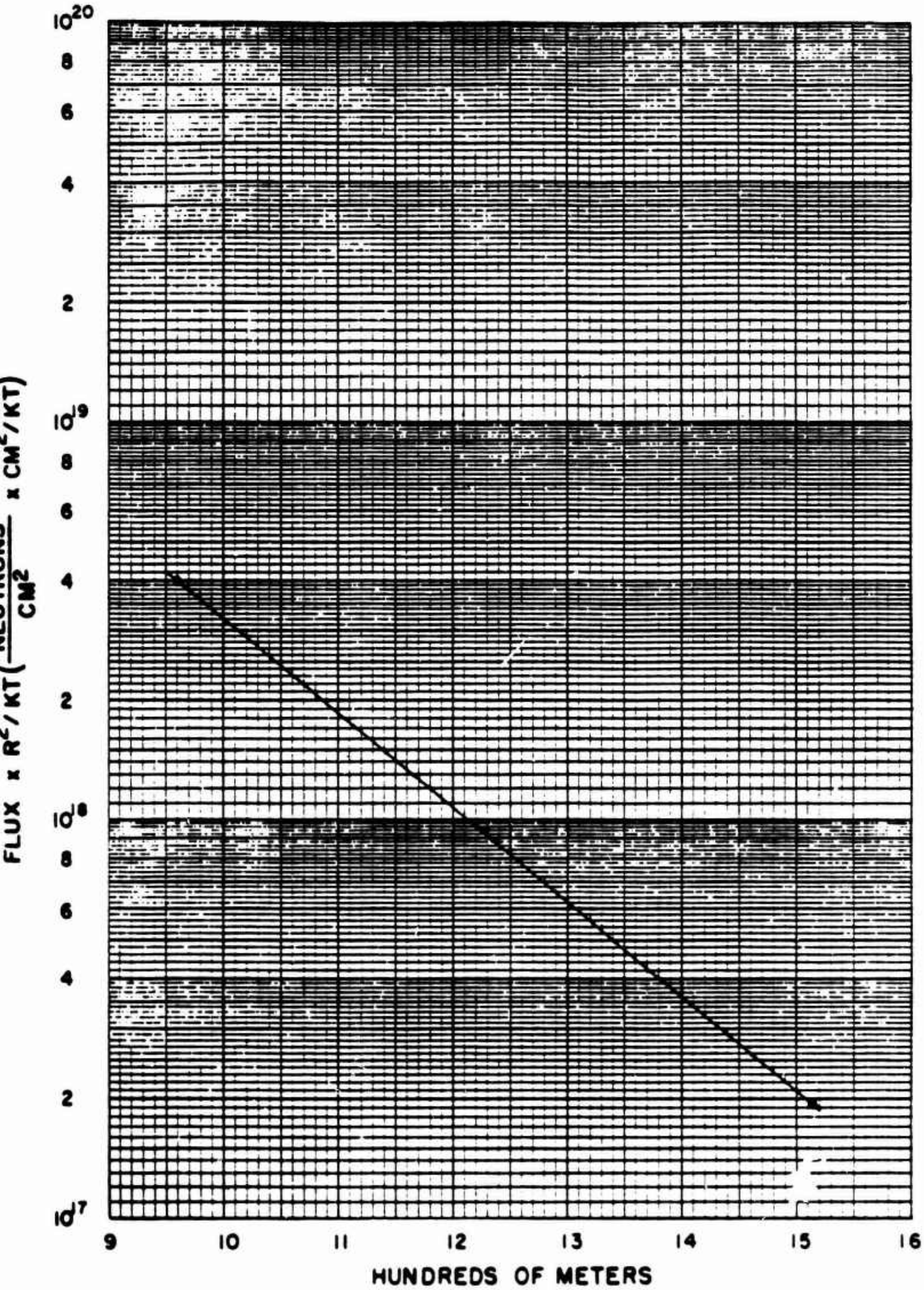

Fig. 5.8 Neutrons measured with iodine on Nectar shot of Operation Castle.

Chapter 6

ZIRCONIUM MEASUREMENTS

Zirconium is used to measure the number of D-T neutrons. It is necessary to expose samples shielded with B^{10} and count annihilation radiation. These precautions, along with the (n, 2n) threshold of 12.5 Mev, make it possible to do a quite clean experiment on D-T neutrons. With our present counting techniques, we have not observed any (n, 2n) activity due to neutrons from a device emitting only fission neutrons.

The D-T neutron spectrum is assumed to be represented by a gaussian curve whose peak is at 14.1 Mev.

Data on zirconium measurements are given in Tables 6.1 through 6.7 and in Figs. 6.1 through 6.8.

Pages 123 through 125 were deleted

TABLE 6.2

D-T NEUTRONS MEASURED WITH ZIRCONIUM ON SNAPPER 1 SHOT

R, meters[a]	Neutrons/cm^2	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2$
Snapper 1 (radiochemistry yield = 19.2 kt)		
323.1	1.51×10^{11}	1.58×10^{20}
327.3	1.60×10^{11}	1.71×10^{20}
332.9	1.71×10^{11}	1.90×10^{20}
340.0	1.76×10^{11}	2.03×10^{20}
348.4	1.98×10^{11}	2.40×10^{20}
370.0	2.08×10^{11}	2.85×10^{20}
393.7	1.71×10^{11}	2.65×10^{20}
422.0	1.45×10^{11}	2.58×10^{20}
453.2	1.18×10^{11}	2.42×10^{20}
486.5	8.73×10^{10}	2.07×10^{20}
521.7	6.77×10^{10}	1.84×10^{20}
558.7	5.18×10^{10}	1.62×10^{20}
596.6	3.70×10^{10}	1.32×10^{20}
636.0	2.94×10^{10}	1.19×10^{20}
675.7	2.27×10^{10}	1.04×10^{20}
757.6	1.14×10^{10}	6.54×10^{19}
841.2	7.27×10^{9}	5.14×10^{19}
884.2	4.95×10^{9}	3.87×10^{19}
926.3	3.41×10^{9}	2.93×10^{19}
969.7	2.97×10^{9}	2.79×10^{19}
1013.0	2.59×10^{9}	2.66×10^{19}
1100.0	1.25×10^{9}	1.51×10^{19}

a. 0 to 460 meters, region of large absorption by bomb mechanisms.

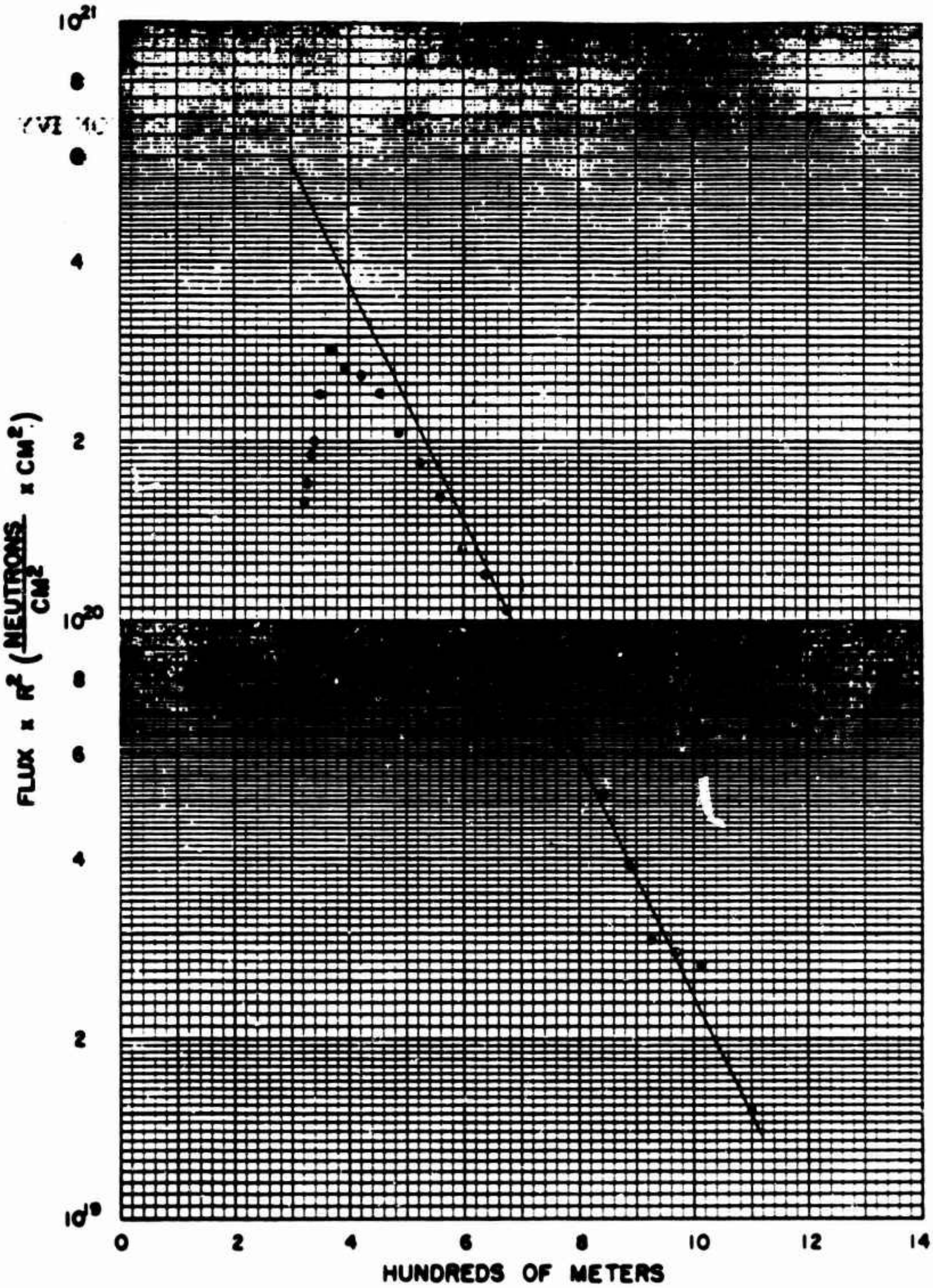

Fig. 6.2 D-T neutrons measured with zirconium on Snapper 1 shot.

TABLE 6.3

D-T NEUTRONS MEASURED WITH ZIRCONIUM ON OPERATION IVY

R, meters	Neutrons/cm^2
Mike (analytic yield = 1.04×10^4 kt)	
1600	4×10^9 [a]
1783	2×10^9 [b]
1920	$0\text{-}3 \times 10^9$
1966	$0\text{-}3 \times 10^9$

a. Probable value, good to only ~50%.

b. Probable value, good to only ~100%.

TABLE 6.4

D-T NEUTRONS MEASURED WITH ZIRCONIUM ON SHOT 6 OF OPERATION UPSHOT-KNOTHOLE

R, meters	Neutrons/cm²	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2$
	UK-6 (radiochemistry yield = 23.0 kt)	
129.3	4.13×10^{11}	6.90×10^{19}
204.5	1.31×10^{11}	5.48×10^{19}
289.1	5.60×10^{10}	4.68×10^{19}
377.0	1.90×10^{10}	2.70×10^{19}
466.3	8.49×10^{9}	1.84×10^{19}
556.0	4.60×10^{9}	1.42×10^{19}
646.5	1.87×10^{9}	7.82×10^{18}
737.0	9.99×10^{8}	5.43×10^{19}
828.0	2.87×10^{9}	1.97×10^{18}
919.0	1.86×10^{8}	1.57×10^{18}

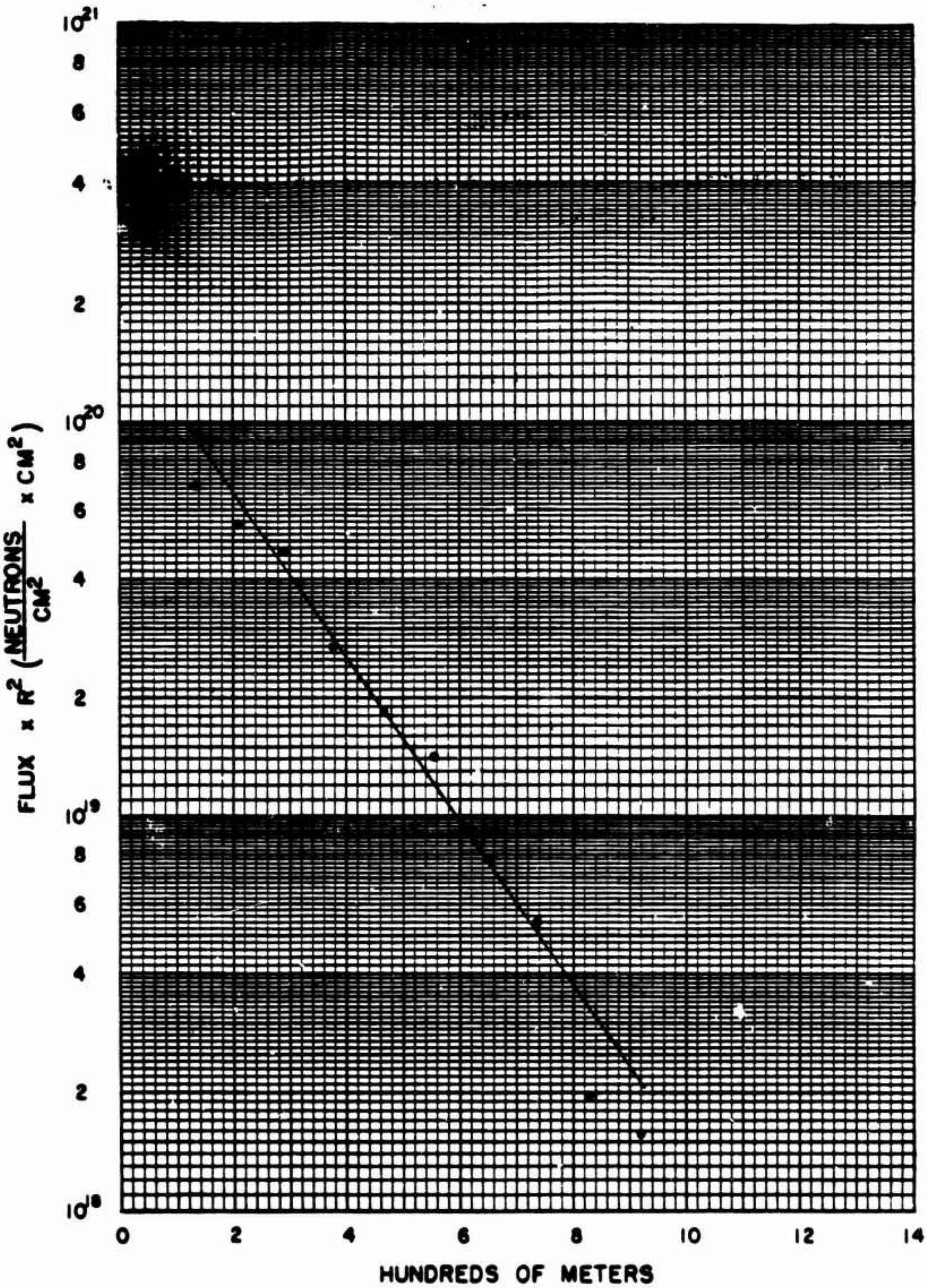

Fig. 6.3 D-T neutrons measured with zirconium on Shot 6 of Operation Upshot-Knothole.

TABLE 6.5

D-T NEUTRONS MEASURED WITH ZIRCONIUM ON OPERATION CASTLE

R, meters	Neutrons/cm^2	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2$
	Bravo (analytic yield = 1.5×10^4 kt)	
1554	2.61×10^{10}	6.29×10^{20}
1646	1.26×10^{10}	3.41×10^{20}
1737	6.81×10^{9}	2.05×10^{20}
1829	4.08×10^{8}	1.36×10^{20}
1920	2.35×10^{8}	8.66×10^{19}
2012	1.05×10^{8}	4.25×10^{19}
2149	8.58×10^{7}	3.96×10^{19}
	Romeo (analytic yield = 1.1×10^4 kt)	
1554	8.81×10^{8}	2.13×10^{20}
1646	6.45×10^{8}	1.75×10^{20}
1737	2.50×10^{8}	7.54×10^{19}
1829	1.43×10^{8}	4.79×10^{19}
1920	1.04×10^{8}	3.82×10^{19}
2149	1.97×10^{7}	9.11×10^{18}
	Union (analytic yield = 7.0×10^3 kt)	
2017	4.32×10^{7}	1.76×10^{19}
2109	2.82×10^{7}	1.25×10^{19}
	Nectar (analytic yield = 1.7×10^3 kt)	
960	4.76×10^{11}	4.39×10^{21}
1515	7.83×10^{8}	1.80×10^{20}

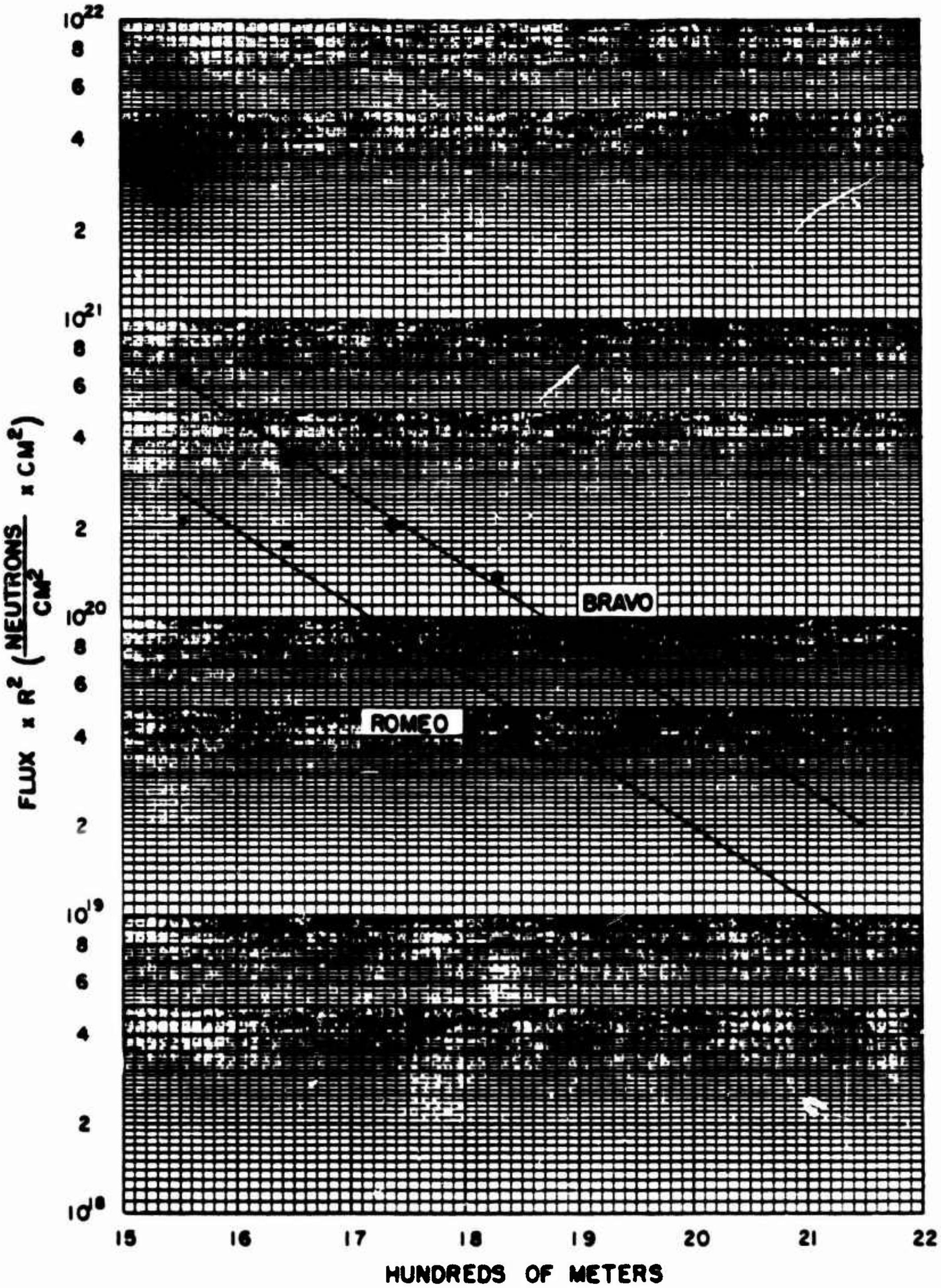

Fig. 6.4 D-T neutrons measured with zirconium on Bravo and Romeo shots of Operation Castle.

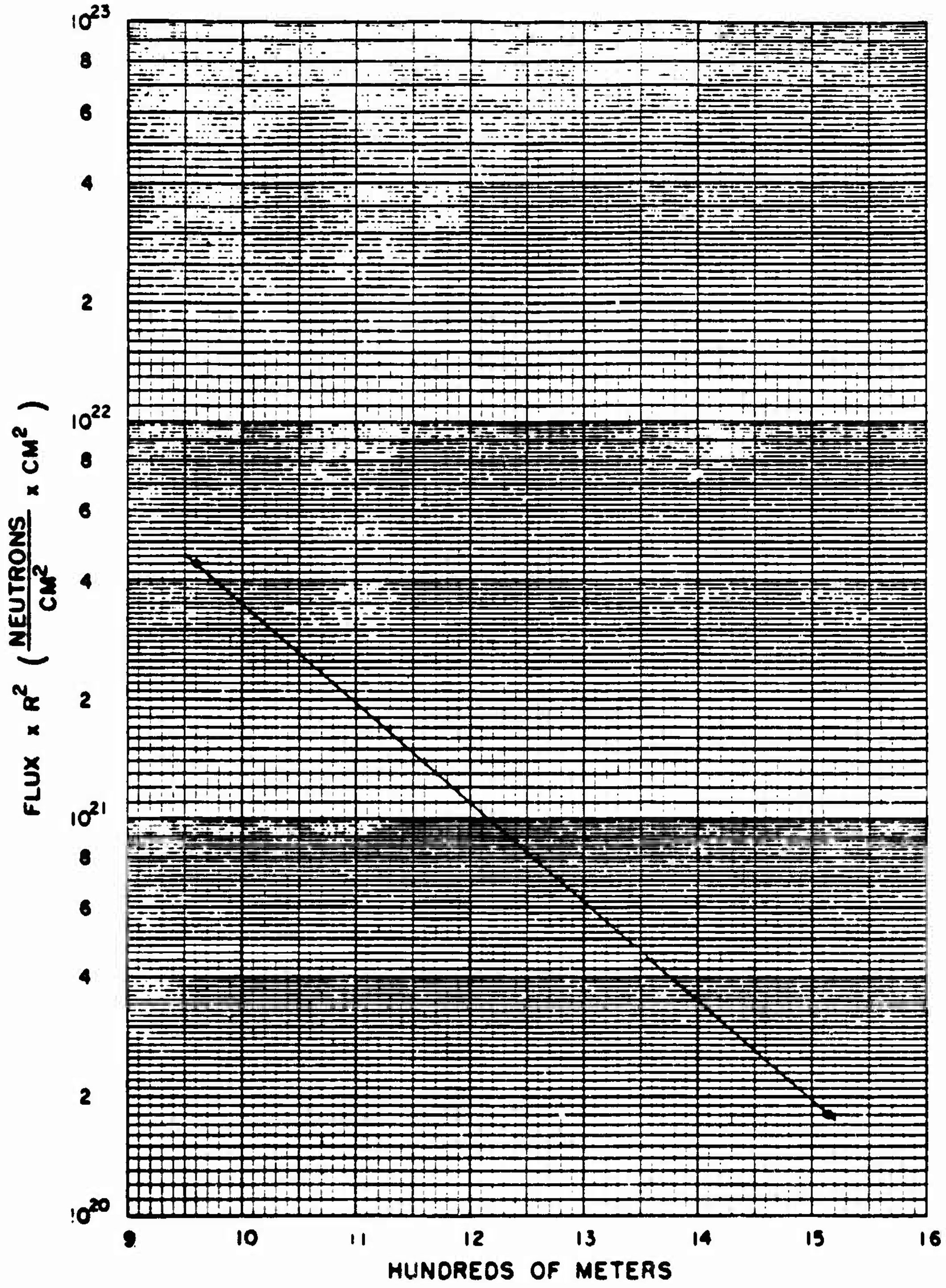

Fig. 6.5 D-T neutrons measured with zirconium on Nectar shot of Operation Castle.

TABLE 6.6

D-T NEUTRONS MEASURED WITH ZIRCONIUM ON OPERATION TEAPOT

R, meters	Neutrons/cm^2	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2$
	Hornet (radiochemistry yield = 3.6 kt)	
95.1	4.27×10^{12}	3.86×10^{20}
97.8	4.08×10^{12}	3.90×10^{20}
248.7	3.01×10^{12}	1.86×10^{20}
289.9	1.74×10^{11}	1.46×10^{20}
377.6	6.68×10^{10}	9.53×10^{19}
421.5	4.07×10^{10}	7.23×10^{19}
466.3	2.81×10^{10}	6.11×10^{19}
556.0	1.21×10^{10}	3.73×10^{19}
645.6	5.33×10^{9}	2.22×10^{19}
731.0	2.59×10^{9}	1.40×10^{19}
828.2	1.39×10^{9}	9.53×10^{18}
	Bee (radiochemistry yield = 8.1 kt)	
158.2	5.33×10^{12}	1.33×10^{21}
169.2	4.00×10^{12}	1.15×10^{21}
186.5	3.27×10^{12}	1.14×10^{21}
354.8	4.50×10^{11}	5.66×10^{20}
396.8	2.82×10^{11}	4.44×10^{20}
438.9	1.96×10^{11}	3.77×10^{20}
482.3	1.34×10^{11}	3.12×10^{20}
569.7	5.55×10^{10}	1.80×10^{20}
658.4	2.71×10^{10}	1.18×10^{20}
747.5	1.50×10^{10}	8.37×10^{19}
837.2	7.58×10^{9}	5.31×10^{19}

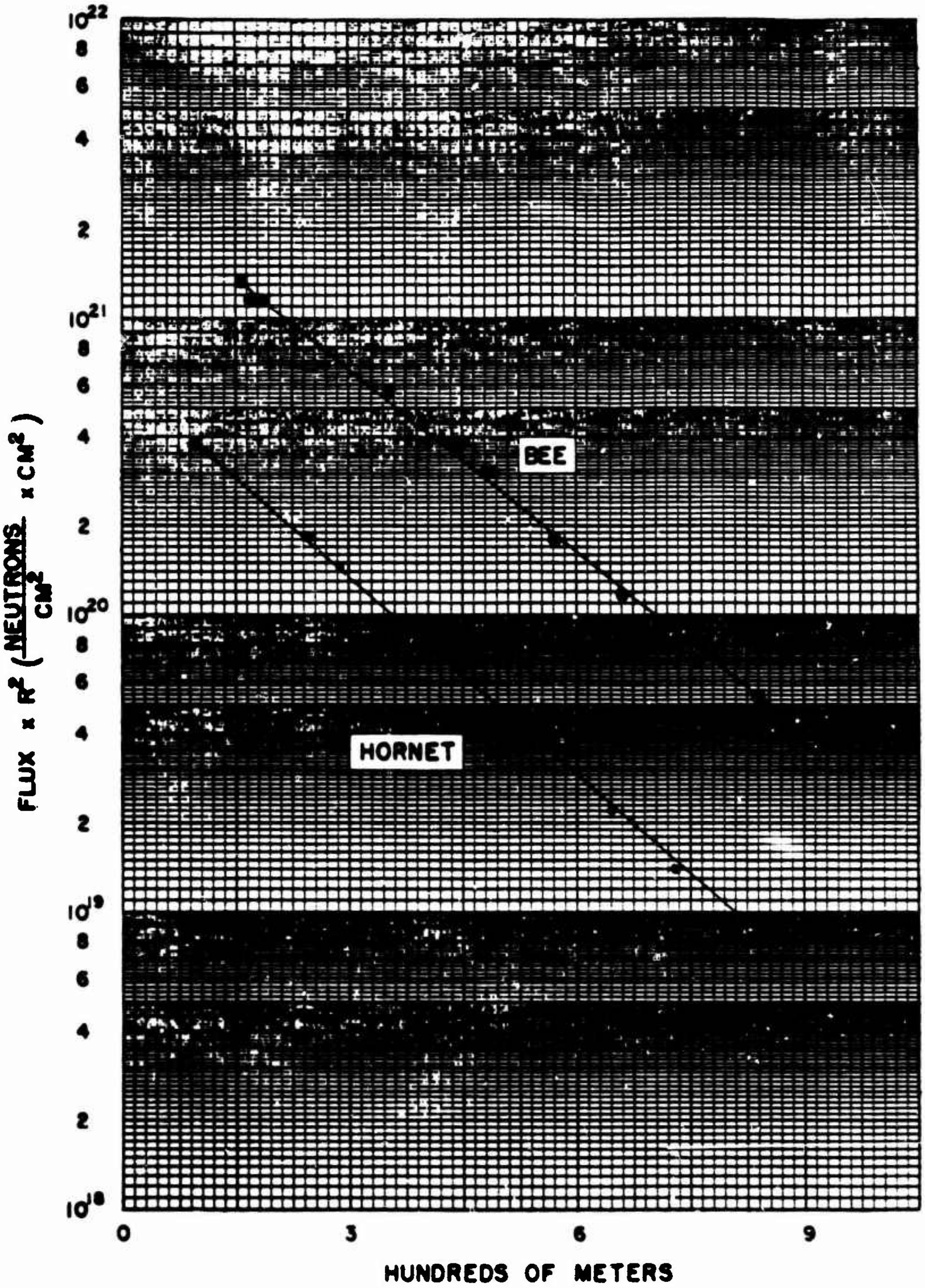

Fig. 6.6 D-T neutrons measured with zirconium on Hornet and Bee shots of Operation Teapot.

TABLE 6.7

D-T NEUTRONS MEASURED WITH ZIRCONIUM ON OPERATION REDWING

R, meters	Neutrons/cm^2	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2$
Lacrosse (radiochemistry yield = 37.8 kt)		
300	5.23×10^{11}	4.71×10^{20}
400	1.60×10^{11}	2.56×10^{20}
500	5.92×10^{10}	1.48×10^{20}
600	2.24×10^{10}	8.05×10^{19}
700	9.29×10^{9}	4.55×10^{19}
800	4.14×10^{9}	2.65×10^{19}
900	1.94×10^{9}	1.57×10^{19}
Seminole (radiochemistry yield = 13.3 kt)		
300	1.80×10^{11}	1.62×10^{20}
400	4.47×10^{10}	7.15×10^{19}
500	1.26×10^{10}	3.16×10^{19}
600	4.72×10^{9}	1.70×10^{19}
700	1.41×10^{9}	6.90×10^{19}
800	5.55×10^{8}	3.55×10^{18}
900	1.11×10^{9}	9.00×10^{17}

Pages 137 through 139 were deleted.

Chapter 7

SPECIAL EXPERIMENTS CONCERNED WITH WEAPON EFFECTS

The tables of data presented in this chapter are mostly self-explanatory. In some cases, members of Group J-12 provided samples for biomedical experimenters and counted them after recovery without any detailed information as to the location of the samples. In such cases, a reference is given to the biomedical report.

The "mouse trap"* data (Table 7.2) are from Operation Ranger, where a few gold samples were arranged so as to drop into a hole just after the blast arrived. These data indicate that about 90% of the thermal neutrons arrived before the sample dropped into the hole.

At Operation Greenhouse, samples were placed on a cable and carried aloft by a balloon. The balloon was burned by thermal radiation and the samples fell to the ground. The sulfur should have already been irradiated, so probably those data are significant for a flux-vs-height measurement. The gold, however, may have received a large amount of the thermal neutron dose while falling and the measurement is thus in doubt. Tables 7.4 and 7.8 give these data.

On Operation Teapot, gold samples were placed in soil and on poles to study the isotropy of thermal neutrons and the albedo of the ground. Tables 7.18 and 7.19 give the data obtained. Samples on the cross arms of the poles faced in the following directions relative to the zero point: 0°, 180°, 90° up, 90° down, 90° side.

On Operation Redwing, gold samples were placed in the ground and below the water surface in the lagoon, the data being listed in Tables 7.20 and 7.21.

Data on measurements for effects experiments for Operations Sandstone through Redwing are given in Tables 7.1 through 7.22. As in previous chapters, data are presented in chronological order, by operation.

*For details see W. E. Ogle, C. L. Cowan, and W. A. Biggers, Report 3 in Operation Ranger Report WT-203, February 14, 1951.

TABLE 7.1

NEUTRONS MEASURED WITH MISCELLANEOUS SULFUR SAMPLES ON OPERATION SANDSTONE

R, meters	Station	Neutrons/cm^2	Remarks
	Yoke (radiochemistry yield = 48.7 kt)		
1646	Inside Gamma C shelter, in line with collimator[a]	2.60×10^8	Error large because sample didn't follow correct decay curve.
1189	Inside Gamma B shelter, in line with collimator[a]	2.30×10^7	No geometry correction has been made for the gamma shelter samples.
649	Inside Gamma A shelter, in line with collimator[a]	1.65×10^9	
1189	In timing station, out of coffin	1.10×10^7	
1189	In timing station, in coffin	5.60×10^6	
457	In water, in animal tank	9.10×10^{10}	
640	Behind 2 in. steel shield	5.60×10^{10}	
	Zebra (radiochemistry yield = 18.2 kt)		
686	Gamma A shelter	2.30×10^8	5° tube, zero absorber. Error large because sample didn't follow correct decay curve.

TABLE 7.1 (continued)

NEUTRONS MEASURED WITH MISCELLANEOUS SULFUR SAMPLES ON OPERATION SANDSTONE

R, meters	Station	Neutrons/cm^2	Remarks
		Zebra (radiochemistry yield = 18.2 kt)	
686	Gamma A shelter	2.30×10^8	5° tube, 3 in. B_4C, 50% calculated attenuation. Error large for same reason as above.
686	Gamma A shelter	4.50×10^7	Background sample, on floor near entrance.
1189	Gamma B shelter	2.30×10^7	Background sample, on forward wall; error large.
1189	Timing station	6.90×10^7	Background sample, on forward wall.
1189	Timing station	1.80×10^8	In coffin.

a. Sandstone Report, Vol. 29, Annex 8, Parts I through V.

TABLE 7.2

NEUTRONS MEASURED WITH MISCELLANEOUS GOLD SAMPLES ON OPERATION RANGER[a]

R, meters	Station	Neutrons/cm^2	Remarks
	Baker I (radiochemistry yield = 7.83 kt)		
501	Foxhole	4.06×10^{11}	
1153	Foxhole	6.31×10^{9}	
	Easy (radiochemistry yield = 1.00 kt)		
333	Block house electrical equipment room	2.70×10^{6}	Shielded by ~10 ft of dirt.
498	Foxhole	1.87×10^{10}	
3036	General Station (2 miles)	8.00×10^{6}	
570	Mouse trap	7.00×10^{7}	Traps were apparently sprung by wind before shot.
977	Mouse trap	2.50×10^{6}	
1864	Mouse trap	1.20×10^{7}	
	Baker II (radiochemistry yield = 7.95 kt)		
537	Mouse trap	3.64×10^{11}	
933	Mouse trap	5.61×10^{9}	
	Fox (radiochemistry yield = 22.2 kt)		
856	Mouse trap	7.55×10^{10}	
1704	Mouse trap	2.36×10^{8}	

a. W. E. Ogle, C. L. Cowan, and W. A. Biggers, Report 3 in Operation Ranger Report WT-203, February 14, 1951.

TABLE 7.3

NEUTRONS MEASURED WITH GOLD FOR BIOMEDICAL EXPERIMENTS ON OPERATION GREENHOUSE[a]

Easy (radiochemistry yield = 46.7 kt)

625	1.95×10^{12}
625	2.33×10^{12}
625	3.26×10^{12}
646	1.81×10^{12}
646	1.11×10^{12} [b]
715	1.01×10^{12}
715	4.15×10^{11}
715	1.20×10^{12}
806	2.27×10^{11}
806	2.61×10^{11}
896	7.67×10^{10}
896	1.20×10^{11}
1010	4.47×10^{10}
1192	1.03×10^{10}

Page 145 was deleted.

TABLE 7.4

NEUTRONS MEASURED WITH GOLD SAMPLES ATTACHED TO BALLOONS ON OPERATION GREENHOUSE[a]

Height, ft	Neutrons/cm^2
Easy (radiochemistry yield = 46.7 kt)	
0	3.61×10^9
50	2.28×10^9
100	2.20×10^9
150	1.72×10^9
200	1.69×10^9
250	1.55×10^9

a. Data are given as thermal neutron flux vs height at 1372 meters.

TABLE 7.7

NEUTRONS MEASURED WITH SULFUR SAMPLES ATTACHED TO BALLOONS ON OPERATION GREENHOUSE[a]

Height, ft	Neutrons/cm^2 [b]
Easy (radiochemistry yield = 46.7 kt)	
150	3.23×10^9
300	4.43×10^9

a. Data are given as flux vs height at 1372 meters.

b. These numbers are good to only ~20%, due to uncertainty in the calibration number.

TABLE 7.8

NEUTRONS MEASURED WITH SULFUR SAMPLES PLACED IN TANKS ON OPERATION GREENHOUSE

R, meters	Position	Neutrons/cm^2 [a]
	Easy (radiochemistry yield = 46.7 kt)	
691	Tank commander's position	1.89×10^{10}
691	Tank driver's position	1.21×10^{10}
918	Tank commander's position	4.54×10^{9}
918	Tank driver's position	2.81×10^{9}

a. These numbers are good to only ~20%, due to uncertainty in the calibration number.

Pages 149 and 150 were deleted.

TABLE 7.11

NEUTRONS MEASURED WITH GOLD SAMPLES PLACED IN SHONKA COLLIMATORS ON OPERATION GREENHOUSE[a]

R, meters	Hole number[b]	Activity, counts/min
	Easy (radiochemistry yield = 46.7 kt)	
715	Bare-7, Cd-1	2,151
715	Bare-11, Cd-9	2,485
715	Floor, bare and Cd	4,637

a. Samples were in Gamma A shelters. For details see Sandstone Report, Vol. 29, Annex 8, Parts I through V.

b. Holes 1, 4 and 7 pointed 1° 53.2' below the bomb. Holes 9 and 11 pointed 8° 6.8' above the bomb. Sulfur was placed in same holes on each shot, but no activity was observed.

Pages 152 through 157 were deleted.

TABLE 7.14

NEUTRONS MEASURED WITH GOLD FOR NRDL BIOMEDICAL EXPERIMENTS ON OPERATION TUMBLER[a]

R, meters	Neutrons/cm^2
Tumbler 3 (radiochemistry yield = 30.7 kt)	
1277	1.24×10^{10}
1305	1.02×10^{10}
1332	8.47×10^{9}
1347	6.77×10^{9}
1362	5.51×10^{9}
1376	4.19×10^{9}
1395	3.37×10^{9}
1415	2.18×10^{9}

a. All samples were shielded with Pb hemispheres 7 in. thick. For details see Robert E. Carter et al., Snapper Project 4.3 Report, WT-528, April 1953.

TABLE 7.15

NEUTRONS MEASURED WITH GOLD FOR NRDL BIOMEDICAL EXPERIMENTS ON OPERATION SNAPPER[a]

R, meters	Shielding	Neutrons/cm^2
Snapper 1 (radiochemistry yield = 19.2 kt)		
774.5	Pb	7.12×10^{11}
861.4	Pb	3.63×10^{11}
883.3	Pb	3.30×10^{11}
925.4	Pb	2.76×10^{11}
953.7	Pb	2.16×10^{11}
996.7	Pb	1.70×10^{11}
1033	Pb	1.52×10^{11}
1076	Pb	1.05×10^{11}
1076	Pb + Cd	5.88×10^{10}
1076	Bi	1.40×10^{11}
1076	Bi + Cd	6.27×10^{10}
1120	Pb	8.59×10^{10}
1186	Pb	5.50×10^{10}
1274	Pb	3.27×10^{10}

a. Shields of Pb and Bi were hemispheres 7 in. thick. The Cd shield was a shell 1/32 in. thick over the outer portion of the Pb or Bi shield. For details see Robert E. Carter et al., Snapper Project 4.3 Report, WT-528, April 1953.

TABLE 7.16

RELATIVE THERMAL NEUTRON FLUX VS DEPTH
IN GROUND MEASURED WITH GOLD ON OPERATION SNAPPER

R, meters	Depth, in.	Activity, counts/min
Snapper 1 (radiochemistry yield = 19.2 kt)		
883.3	2	9.13×10^5
883.3	4	8.26×10^5
883.3	6	6.26×10^5
953.7	2	5.60×10^5
953.7	4	4.87×10^5
953.7	6	3.62×10^5
1076	2	2.52×10^5
1076	4	2.13×10^5
1076	6	1.57×10^5

TABLE 7.17

NEUTRONS MEASURED WITH SULFUR FOR NRDL BIOMEDICAL EXPERIMENTS ON OPERATION SNAPPER[a]

R, meters	Depth, in.	Shielding	Neutrons/cm^2
Snapper 1 (radiochemistry yield = 19.2 kt)			
774.5		Pb	3.92×10^{10}
861.4		Pb	2.11×10^{10}
883.3		Pb	2.12×10^{10}
925.4		Pb	1.63×10^{10}
953.7		Pb	1.36×10^{10}
996.7		Pb	8.99×10^{9}
1033		Pb	8.26×10^{9}
1076		Pb	5.85×10^{9}
1076		Pb + Cd	4.39×10^{9}
1076		Bi	5.51×10^{9}
1076		Bi + Cd	5.25×10^{9}
1120		Pb	4.01×10^{9}
1186		Pb	3.00×10^{9}
1274		Pb	1.50×10^{9}
883.3	2	Pb	1.04×10^{11} [b]
883.3	4		Sample not recovered
883.3	6	Pb	4.76×10^{10} [b]
953.7	2	Pb	4.65×10^{10} [b]
953.7	4	Pb	3.67×10^{10} [b]
953.7	6	Pb	1.30×10^{10} [b]
1076	2	Pb	2.98×10^{10} [b]
1076	4	Pb	1.53×10^{10} [b]
1076	6	Pb	8.49×10^{9} [b]

a. Shields of Pb and Bi were hemispheres 7 in. thick. The Cd shield was a shell 1/32 in. thick over the outer portion of the Pb or Bi shield. For details see Robert E. Carter et al., Snapper Project 4.3 Report, WT-528, April 1953.

b. Sample not contained in standard sample holder.

TABLE 7.18

RELATIVE THERMAL NEUTRON FLUX VS DIRECTION AND HEIGHT ABOVE GROUND MEASURED WITH GOLD FOR MOTH SHOT[a] OF OPERATION TEAPOT

Direction Sample Was Facing	Distance above Ground, ft	Relative Thermal Neutron Flux
Samples at ground distance of 274.3 meters		
Non-directional	0.5	1.24×10^7
Non-directional	12.0	1.19×10^7
Non-directional	24.0	1.16×10^7
Down	0.5	6.97×10^6
Down	12.0	7.04×10^6
Down	24.0	6.13×10^6
Up	0.5	5.41×10^6
Up	12.0	6.09×10^6
Up	24.0	4.87×10^6
Front	0.5	5.94×10^6
Front	12.0	6.86×10^6
Front	24.0	6.58×10^6
Back	0.5	5.84×10^6
Back	12.0	5.09×10^6
Back	24.0	5.08×10^6
Left	12.0	6.27×10^6
Right	12.0	6.56×10^6
Samples at ground distance of 731.5 meters		
Non-directional	0.5	4.60×10^4
Non-directional	12.0	4.56×10^4
Non-directional	24.0	4.22×10^4
Down	0.5	2.94×10^4
Down	12.0	2.72×10^4
Down	24.0	2.69×10^4
Up	0.5	1.84×10^4
Up	12.0	1.94×10^4
Up	24.0	1.90×10^4

TABLE 7.18 (continued)

RELATIVE THERMAL NEUTRON FLUX VS DIRECTION AND HEIGHT ABOVE GROUND MEASURED WITH GOLD FOR MOTH SHOT[a] OF OPERATION TEAPOT

Direction Sample Was Facing	Distance above Ground, ft	Relative Thermal Neutron Flux
Samples at ground distance of 731.5 meters		
Front	0.5	2.52×10^4
Front	12.0	1.98×10^4
Front	24.0	2.36×10^4
Back	0.5	2.29×10^4
Back	12.0	1.88×10^4
Back	24.0	1.91×10^4
Left	12.0	2.18×10^4
Right	12.0	2.84×10^4

a. Radiochemistry yield = 2.39 kt; height of burst was 91.44 meters (300 ft tower).

TABLE 7.19

RELATIVE THERMAL NEUTRON FLUX VS DEPTH IN GROUND MEASURED WITH GOLD ON OPERATION TEAPOT

Ground Distance, meters	Depth, in.	Relative Thermal Neutron Flux
Moth[a] (radiochemistry yield = 2.39 kt)		
731.5	0	8.45×10^{4}
731.5	1	1.19×10^{5}
731.5	2	1.27×10^{5}
731.5	4	1.15×10^{5}
731.5	6	9.39×10^{4}
731.5	8	6.84×10^{4}
274.3	0	2.04×10^{7}
274.3	1	2.43×10^{7}
274.3	2	2.38×10^{7}
274.3	4	1.82×10^{7}
274.3	6	1.27×10^{7}
274.3	8	7.97×10^{6}
Wasp Prime[b] (radiochemistry yield = 3.2 kt)		
712.3	0	6.76×10^{5}
712.3	4	1.00×10^{6}
712.3	8	6.62×10^{5}
712.3	12	3.58×10^{5}
712.3	16	1.59×10^{5}
712.3	20	7.26×10^{4}
482.2	0	3.39×10^{6}
482.2	4	5.09×10^{6}
482.2	8	3.29×10^{6}
482.2	12	1.61×10^{6}
482.2	16	6.81×10^{5}
482.2	20	2.97×10^{5}

TABLE 7.19 (continued)

RELATIVE THERMAL NEUTRON FLUX VS DEPTH IN GROUND MEASURED WITH GOLD ON OPERATION TEAPOT

Ground Distance, meters	Depth, in.	Relative Thermal Neutron Flux
	Wasp Prime[b] (radiochemistry yield = 3.2 kt)	
252.7	0	1.80×10^7
252.7	4	2.90×10^7
252.7	8	1.82×10^7
252.7	12	1.05×10^7
252.7	16	5.10×10^6
252.7	20	2.21×10^6

a. Height of burst was 91.44 meters (300 ft tower).

b. Height of burst was 225.2 meters (air drop).

Pages 166 and 167 were deleted.

Chapter 8

SPECIAL EXPERIMENTS FOR DIAGNOSTIC PROJECTS

Phonex, a nuclear emulsion technique of neutron spectra measurements* in good geometry, was performed at Greenhouse, Upshot-Knothole, and Redwing. Figures 8.1 and 8.2 show the spectra emerging from the device for Greenhouse Dog, Easy, George, and Item. Measurements were made at various distances and extrapolated back to the device.

Function-of-time experiments were made at Greenhouse, Buster-Jangle, and Tumbler-Snapper. Figures 8.3 through 8.22 show some results of these measurements. Only thermal neutrons vs time are shown, the detector being U^{235}. Except on Tumbler-Snapper the U^{238} measurements are discounted because the degree of depletion has been found to be insufficient. The samples were calibrated to a 36 hr counting rate because it was thought that 36 hr after shot time was a reasonable time to expect to start counting.

On Greenhouse and Upshot-Knothole, threshold detectors were placed in two types of collimated systems. Tables 8.1 through 8.7 show these results.

The collimators used by Louis Rosen of LASL on Greenhouse and Donald D. Phillips of LASL on Upshot-Knothole were steel pipes 36 in. long and 1/2 in. inside diameter, suitably shielded. They are described in WT-68. Detectors were placed in these collimators.

Collimated channels looking at internal components of devices were used by Bob E. Watt of LASL during Upshot-Knothole. These channels terminated in Watt's detector stations (Stations 1-480 and 4-480), where sulfur and zirconium detectors were placed. The channels and stations are described in L. B. Seely et al., Upshot-Knothole Handbook of Diagnostic Experiments, Report WT-707, February 1953.

---

*J. C. Allred, D. D. Phillips, and L. Rosen, Greenhouse Report WT-68, Annex 1.5, Part II, Sec. 2, January 1952.

Pages 169 through 190 were deleted.

TABLE 8.1

NEUTRONS MEASURED WITH SULFUR SAMPLES PLACED IN ROSEN COLLIMATORS ON OPERATION GREENHOUSE[a]

R, meters	Lead Shielding, in.	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
	Easy (radiochemistry yield = 46.7 kt)		
205.1	2	1.25×10^{10}	5.28×10^{18}
205.1	0	3.36×10^{10}	1.41×10^{19}
377.0	0	4.43×10^{9}	6.30×10^{18}
556.0	2	1.67×10^{8}	5.16×10^{17}
556.0	0	6.04×10^{8}	1.87×10^{18}
737.0	0	1.17×10^{8}	6.36×10^{17}

Page 192 was deleted.

TABLE 8.2

NEUTRONS MEASURED WITH IODINE SAMPLES PLACED IN ROSEN COLLIMATORS ON OPERATION GREENHOUSE

R, meters	Lead Shielding, in.	Neutrons/cm^2/kt	$\frac{\text{Neutrons}}{\text{cm}^2} \times \text{cm}^2/\text{kt}$
		Easy (radiochemistry yield = 46.7 kt)	
204.8	0	3.96×10^8	1.66×10^{17}
204.8	2	2.07×10^8	8.68×10^{16}
376.7	0	4.27×10^7	6.06×10^{16}
555.0	0	1.37×10^7	4.22×10^{16}
555.0	2	1.52×10^7	4.68×10^{16}

TABLE 8.4

NEUTRONS MEASURED WITH SULFUR AND ZIRCONIUM SAMPLES PLACED IN WATT'S DETECTOR STATIONS ON SHOT 2 OF OPERATION UPSHOT-KNOTHOLE

Channel	Sulfur, neutrons/cm^2/kt	Zirconium, neutrons/cm^2
UK-2 (radiochemistry yield = 24.2 kt)		
	5.76×10^5 [a]	0
	3.13×10^7	2×10^7 [a]
	3.29×10^6 [a]	0
	0	0

a. Due to low counting rates, these numbers are good to only ~100%.

TABLE 8.5

NEUTRONS MEASURED WITH SULFUR AND ZIRCONIUM SAMPLES PLACED IN PHILLIPS' COLLIMATORS ON SHOT 6 OF OPERATION UPSHOT-KNOTHOLE

R, meters	Sulfur, neutrons/cm^2/kt	Zirconium, neutrons/cm^2
UK-6 (radiochemistry yield = 23.0 kt)		
412.3	4.01×10^9	1.8×10^{10}
608.3	7.57×10^8	2.0×10^9 [a]
806.2	1.68×10^8	6.0×10^8 [a]

a. Due to low counting rates, these numbers are good to only ~50% to ~100%.

TABLE 8.6

NEUTRONS MEASURED WITH SMALL AND LARGE SULFUR SAMPLES IN COLLIMATED GEOMETRY ON SHOT 7 OF OPERATION UPSHOT-KNOTHOLE

Collimation	Channel	R, meters	Small Samples, neutrons/cm^2/kt	Large Samples, neutrons/cm^2/kt
UK-7 (radiochemistry yield = 41.8 kt)				
Phillips		875.1	5.50×10^7	
Phillips		875.1	4.07×10^7	
Watt		914.4	2.63×10^7	2.78×10^7
Watt		914.4	2.32×10^7	2.78×10^7
Watt		914.4	2.32×10^7	2.44×10^7
Watt		914.4	0	0

TABLE 8.7

NEUTRONS MEASURED WITH ZIRCONIUM SAMPLES IN COLLIMATED GEOMETRY ON SHOT 7 OF OPERATION UPSHOT-KNOTHOLE

Collimation	Channel	R, meters	Zirconium,[a] neutrons/cm^2
UK-7 (radiochemistry yield = 41.8 kt)			
Phillips		875.1	1.4×10^8
Phillips		875.1	2.3×10^8
Watt		914.4	3.0×10^7
Watt		914.4	2.4×10^8
Watt		914.4	2.1×10^8
Watt		914.4	0

a. Due to low counting rates, these numbers are good to only ~50 to ~100%.

Chapter 9

NEUTRON CALCULATIONS

A Monte Carlo calculation on neutron distribution in space, time, and energy has been underway for about two years. Due to the time required for field work, it has progressed rather slowly. The problem originally was coded for the IBM 701 but must now be recoded for the 704. Some additional input is being added.

The problem, as now planned, will contain the following input data:

1. Chemical composition of Nevada air and ground.
2. Assumed point source 300 ft above the ground-air interface.
3. Calculated shock wave for 15 kt device to give air density vs time and radius.
4. Neutron cross sections from thermal to 14 Mev. These include the total, elastic scattering, and inelastic scattering cross sections and angular distribution of scattered neutrons for the elements of importance.
5. Initial energy of neutrons in the range from 0.25 kev to 14 Mev. Each energy will be run as a separate problem.

The following information will be included in the output:

1. Flux at the ground-air interface vs range, energy, and time.
2. Total number of neutrons entering ground vs range, energy, and time.
3. Total number of neutrons leaving ground vs range, energy, and time.
4. Number of neutron collisions ahead of shock wave.*
5. Number of neutron collisions behind shock wave.
6. Number of neutron collisions in shock wave and the number of these in which the neutron was going away from the source.

---

*We define the shock wave to be that portion that has a density greater than the ambient density.

In order to use this information, one must first have a knowledge of the spectrum of neutrons leaving a device. We feel that a reasonable guess can be made for this, and we are working on techniques to give an experimental value for the spectra seen in poor geometry as a function of distance from the device.

The code may be modified, if desired, to give the flux through concentric spheres, change or omit shock wave input, remove the ground-air interface, or obtain other information.

Chapter 10

CONCLUSIONS AND RECOMMENDATIONS

In general, it is believed that the measurements of flux at a particular station have probable errors no greater than about 10%. There are some exceptions to this where unforeseen or uncontrollable events led to widely scattered data, as some of the Castle data.

The way in which the data are interpreted, however, is a moot question. Sulfur, for example, is calibrated at 14.1 Mev. The sulfur data given previously should, therefore, not be considered to be the number of neutrons above the sulfur threshold, but the equivalent number of 14.1 Mev neutrons. From the cross-section curve in Fig. 4.1, it is clear that the actual number of neutrons represented is a function of the spectrum, and particularly, a function of whether or not the device tested emitted a large number of D-T neutrons.

Another point of interest is the question of how a plot of NVT $\times$ R^2 vs R^2 behaves near R = 0. It is indicated from recent data on a one-point detonation (Fig. 10.1) that the sulfur curve bends down. If this is true, it seems likely that the degree of bending is a function of the spectrum. It also seems likely that the zirconium curve should bend down, although perhaps not so much as the sulfur.

One of the things most needed to interpret the data is a knowledge of the neutron spectrum in poor geometry. Although the fission foil technique seems to give numbers proportional to biological dose, we question their present applicability to obtaining absolute numbers of neutrons. Phonex is a possible technique, but presents many problems in obtaining a poor geometry spectrum. This Group is now considering a method (Monex) which will be tested at Plumbbob. A disadvantage of the method is that it makes use of the subtraction technique similar to that of threshold detectors, which may lead to large probable errors.

Another item deserving study is the shape of the plots of NVT $\times$ R^2 vs R^2 at close distances. This is usually difficult to do experimentally in the field because of recovery problems for close samples.

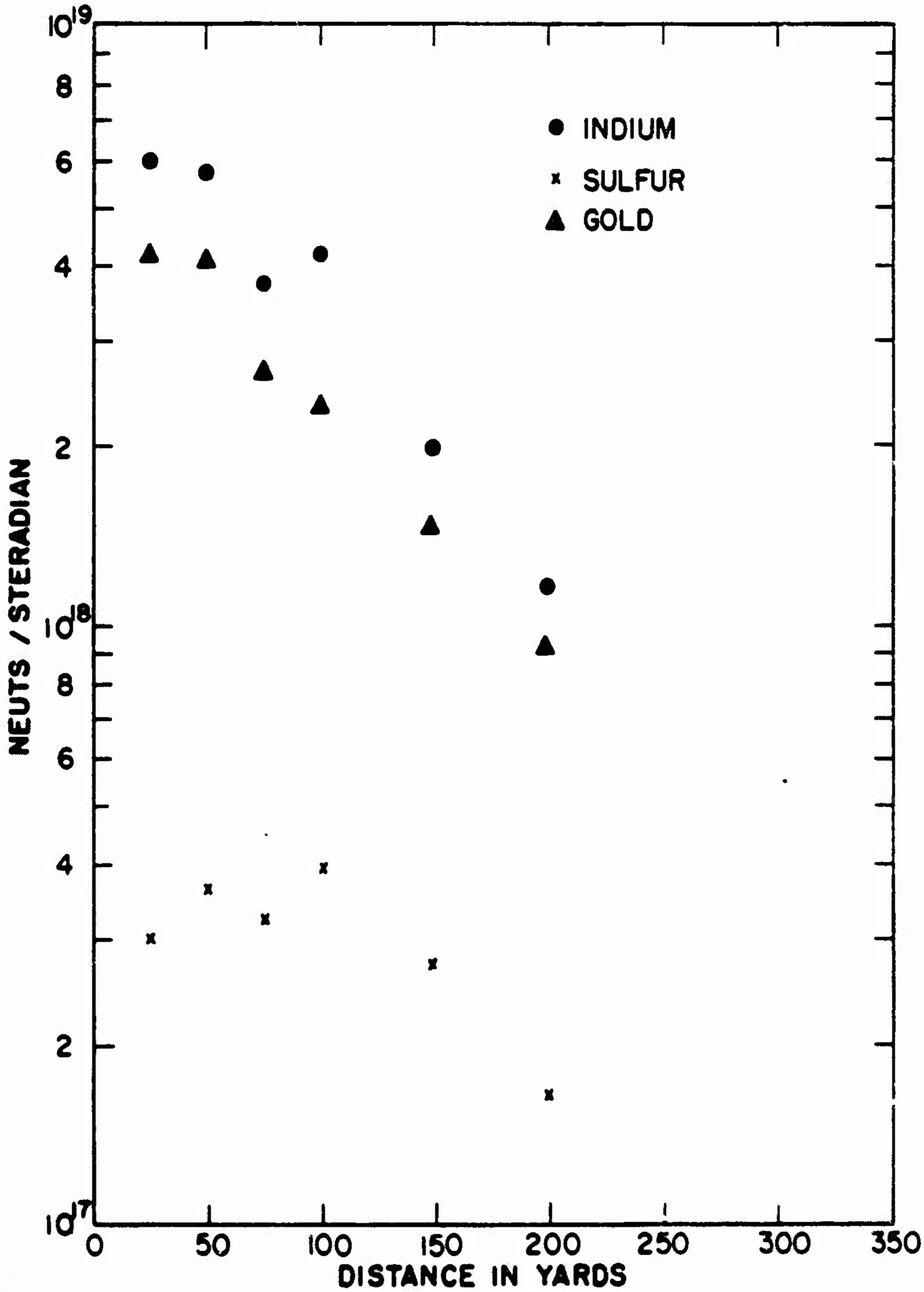

Fig. 10.1 Neutrons measured with indium, sulfur, and gold on a one-point detonation.

Pages 201 and 202 were deleted.